

YEAR IN IDEAS: WHAT TO EXPECT IN 2015

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WARFARE—AND WE
GOT TO TEST THEM

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TOO?**
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MIGHT
SURPRISE
YOU

THE NEW

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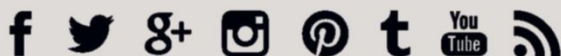
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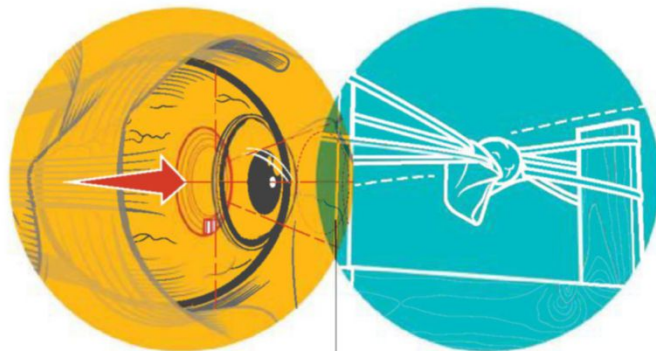
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VENN DIAGRAM

In which we compare two seemingly contradictory stories from this month's issue:



Pressure-sensing lenses (p. 35)

- You put them in your eyes—on purpose.
- They help detect and prevent glaucoma.

- They carefully cradle small white spheres.

Snowball slingshots (p. 63)

- Don't shoot your eye out!
- They defend your fort against invasion.

UPDATED

Each year, we predict the biggest stories in science and technology for the next 12 months. So, how did we do in 2014?

We reported:

The U.S. Army would use Field Deployable Hydrolysis Systems (FDHS) to neutralize chemical warfare agents.

Tokyo Electric Power Company would build an underground ice wall to sequester contaminated water from the Fukushima nuclear power plant.

Infectious diseases like whooping cough and measles would reemerge on a larger scale.

What happened:

FDHS aboard U.S. ships had disposed of many of Syria's chemical weapons by mid-August.

The company tried, but the ice wall failed because temperatures didn't drop low enough to freeze the radioactive groundwater.

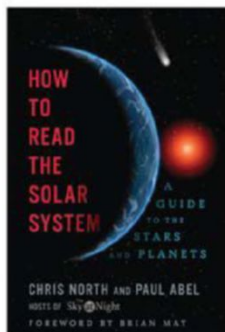
We were all too correct; plus, an Ebola outbreak raced through West Africa before jumping to the U.S. and Europe.

(UN)NECESSARY KICKSTARTER OF THE MONTH

IllumiBowl Clip-On Toilet Night Light (Motion-Activated)

TINY BOOK REVIEW

Many very existential minds just stare upward nightly.



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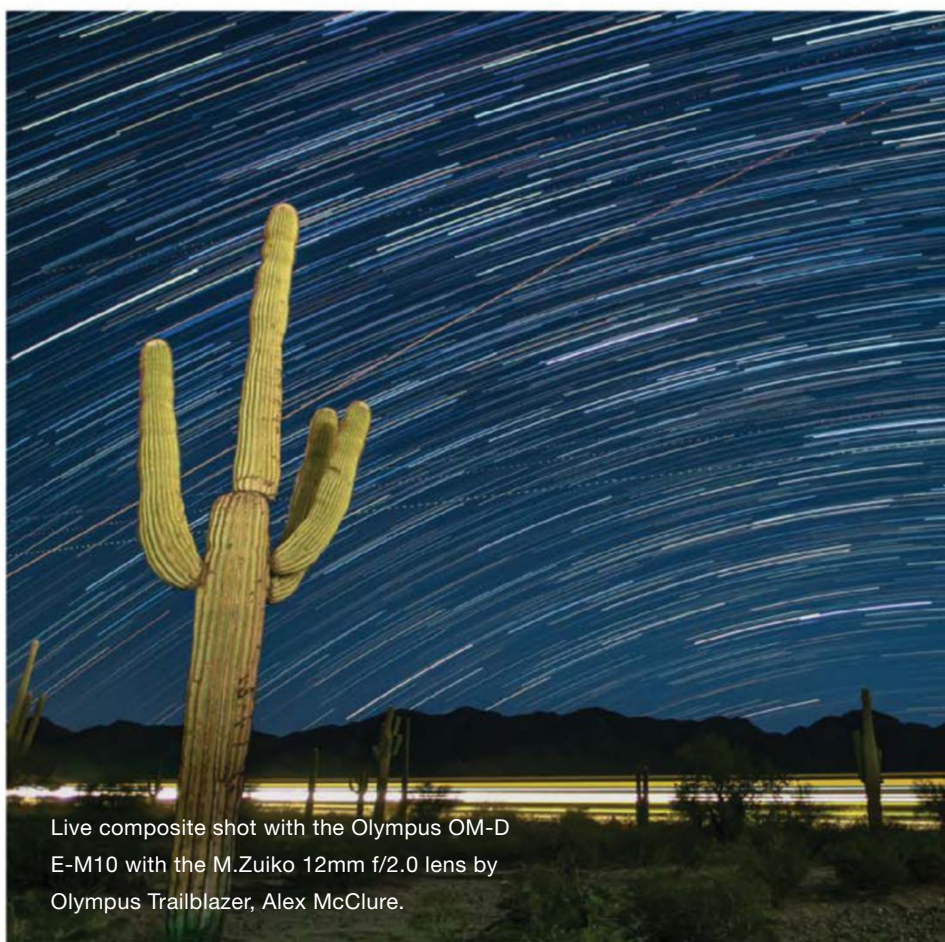
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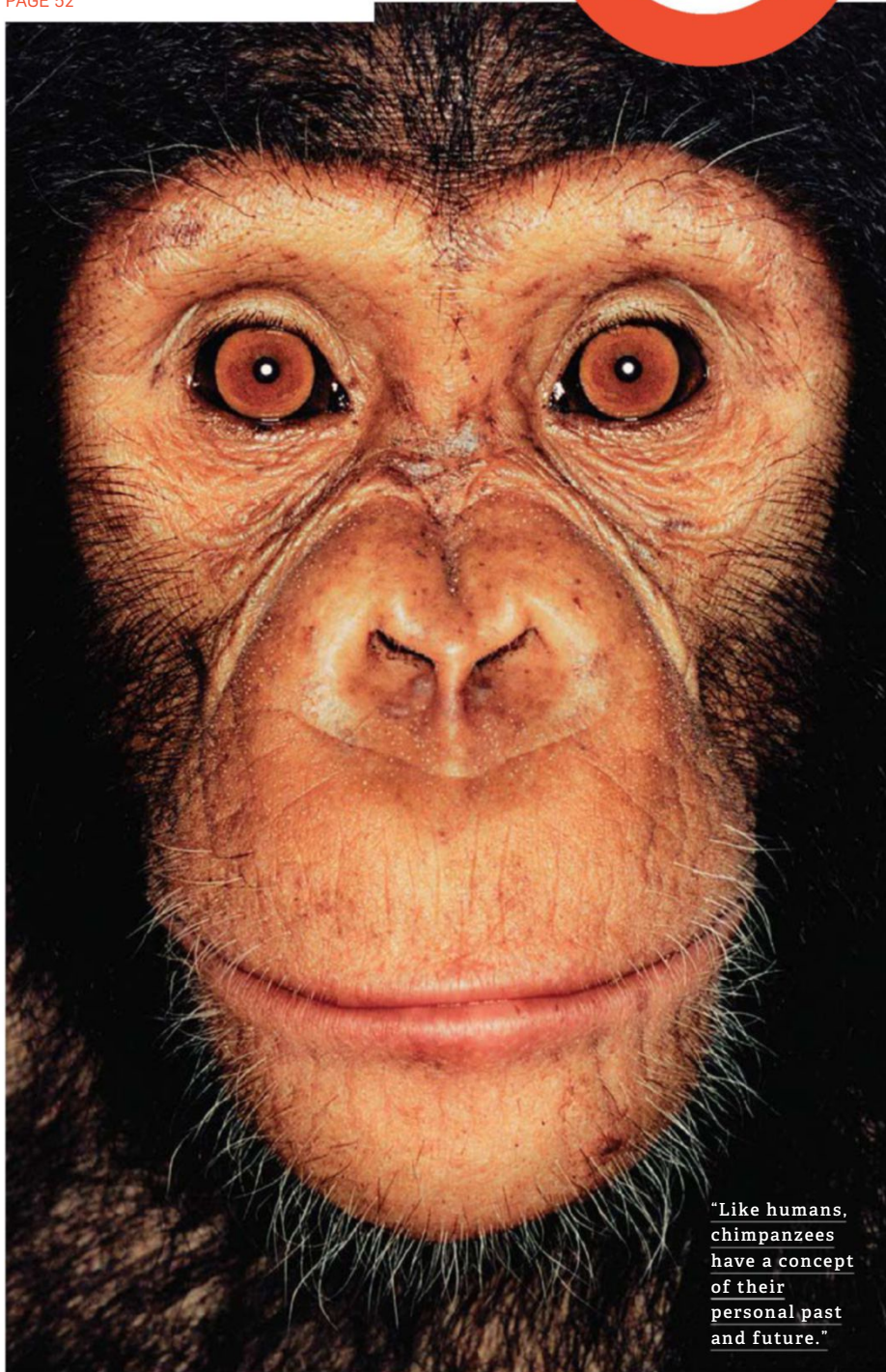
Move into a New World

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Humans have always seen themselves as distinct from other creatures. New research forces us to reconsider that position.

CHARLES SIEBERT

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"Like humans, chimpanzees have a concept of their personal past and future."

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Ebola vaccines, dwarf planets, virtual-reality headsets, and more. Here's what science has in store for 2015.

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Inside the New Stealth Arsenal

A top secret class of autonomous drones is changing the way war is waged.

ERIC ADAMS

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Maker, Inc.How General Electric, Local Motors, and DIY inventors are rebuilding American manufacturing. **TOM FOSTER**

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**ON THE COVER** Taranis, an autonomous craft by BAE Systems, evades radar with a superstealth design. Illustration by **Graham Murdoch**

The Power of Ideas

On October 28, an Antares rocket on a resupply mission to the International Space Station exploded 15 seconds after launch in coastal Virginia. Three days later, SpaceShipTwo, the experimental spacecraft from Virgin Galactic, disintegrated 50,000 feet over the Mojave Desert. It was a terrible week

for private space: One dead. One injured. Hundreds of millions of dollars' worth of technology, supplies, and experiments destroyed.

Not surprisingly, the incidents set off a round of furious hair tearing and teeth gnashing over the future of private space. Could the nascent industry survive unmitigated disasters? The answer came less than two weeks later, when Orbital Sciences, which manages the Antares, and Virgin Galactic announced plans to move

forward. Orbital had selected a new engine to replace the flawed AJ26 on the Antares, and Virgin was hard at work on a new SpaceShipTwo. Both say they are aiming for flights in the spring.

That the companies were able to get back to business so quickly speaks volumes about their tenacity and resolve. It also bodes well for private enterprise in low-Earth orbit. At this point, no one knows what the commercial space industry will look like. It may include

tourism and Virgin Galactic. It may not. It may include asteroid mining and Planetary Resources (whose Arkyd 3 satellite was lost on the Antares). It's too early to tell. The only certainty is that private space is growing—and it's too big and compelling an idea to stop.

The renowned French writer Victor Hugo once wrote, "One can resist an invasion of armies; one cannot resist an invasion of ideas." That's a pretty grandiose sentiment, granted. And Hugo likely meant it in a political and social context. But the fact is, he's right. Whether private space or Grumpy Cat, ideas are incredibly powerful—they're cheap to develop, easy to distribute, and can never be taken back. The best ones grow fast and tend to stick in people's minds.

More than anything else, *Popular Science* is a magazine about ideas, and every issue, we try to identify ones that could change the world in ways big and small. Of all our coverage, perhaps no single story better reflects that focus than our annual Year in Ideas feature. In it, we predict the 10 most important concepts for the coming year. Among



this issue's standouts, we examine water scarcity in the West, the significance of the upcoming Ceres and Pluto missions, and the rapid development of Ebola vaccines. We also include private space. Next year, NASA, working with Bigelow Aerospace, will begin testing inflatable space habitats, a meaningful step toward the development of a commercial space station. Even with setbacks, powerful ideas only grow.

Enjoy the issue.

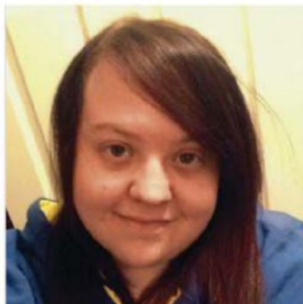
Cliff Ransom
Editor in Chief

Contributors



Tom Foster

As he approached Louisville, Kentucky, contributing editor Tom Foster peered out his plane window to see a vast complex of buildings: General Electric's Appliance Park. "From overhead you notice its sprawl," he says. The facility, a relic of GE's past, could also inform the company's future. In "Maker, Inc." (page 56), Foster reports on GE's FirstBuild, a new hacker-inspired R&D project.



Brittany Vincent

Brittany Vincent has built her career on videogames: She spends eight hours a day playing, watching, or writing about them. For "How to Stream Like a Pro Gamer" (page 22), she tested the best new hardware out there. When asked what emerging technology most excites her, Vincent has a ready answer: virtual reality. "It gives you the chance to explore countless worlds," she says.



Ray Lego

Composing images that illustrate how to make a crossbow or forge knives might be easy in a studio. But try it in a home workshop full of soot and sparks. That's the challenge Ray Lego faced when photographing "A Reflux Still for Making Moonshine" (page 67). Lego documented Rebuild columnist Hackett as he assembled a homemade still—for postapocalyptic uses only, of course.



Charles Siebert

In "Animals Like Us" (page 52), Charles Siebert draws from his decades of reporting on animals and nature to explore the science of personhood. A growing body of research has led lawyers to take on unlikely clients: chimps. Siebert has been following lawyer Steven Wise's legal defense of Tommy the chimp closely. "It's like the modern version of the Scopes Monkey Trial," he says.

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A Smarter, Fairer SAT

In spring 2016, teenagers worldwide will encounter a new college-entrance exam. A major difference between the existing and redesigned tests is how questions are framed. The College Board, which administers the SAT, tasked its assessment team with creating questions that shift the emphasis from rote memorization to skills that are taught in the classroom. Here's how they did it.

A TEST OF MENTAL ENDURANCE

The new SAT is the longest yet—stretching to 3 hours 50 minutes with the optional essay (here shown in pink) against the existing test (middle ring) and the pre-2005 version (outer ring).



Assessment team member Jim Patterson dissects two sample questions old and new—to explain the logic behind the redesigned test.

Old Question

There is no doubt that Larry is a genius. — In search of better

(A) ingenious (B) dilettante (C) piffling (D) promiscuous (E) mendacious

THE SENTENCE is written in a way that is allusive and obscure. The sentence is written in a way that is allusive and obscure.

SOME PEOPLE would know that answer. It's unlikely that students would know that answer.

MUCH OF this high school vocabulary is not only in the vocabulary of the word "ingenious" but also in the vocabulary of the word "ingenious".

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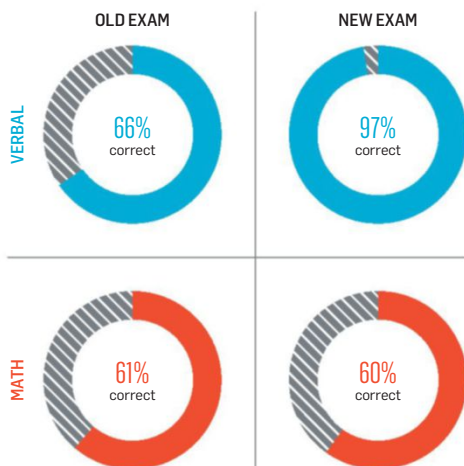
WORD TO THE WISE

The new question from "A Smarter, Fairer SAT" [November 2014] is redundant. Even without the word *intense*, *clustering* means *concentrated*. If one does not know the words *dilettante*, *pilferer*, or *raconteur*, then that person is not a reader or is too lazy to use a dictionary. What if this person becomes a surgeon operating on the "thingie" next to your "whatchamacallit"?

Paul Koskovich, Canton, Ohio

APTITUDE TEST

Here's how 310 readers did on our highly abbreviated SAT exam, posted at *popsci.com*. * The quiz included a verbal and a math question from both the current exam and the forthcoming redesign. Nearly a third of the respondents aced it, getting all four right. Send those folks diplomas!



*Results as of November 11, 2014

TIME-TESTED TRICK

As an Army Security Agency Morse code intercept operator in the fifties, I recorded nearly every coded radio signal in the ether. The room would often reverberate with the sound of a hand slapping a rack of hardware in an attempt to improve reception. We called it "third echelon maintenance." It often worked, as noted in "Can You Fix a Machine by Smacking It?" [November 2014].

Low Yeager, Marietta, Ohio

SOCIAL FAIL

I find it sad that people are relying on robots, like those in "Friend for Life" [November 2014], to fill the need for human emotion. Robots are already doing away with jobs. So what is left if we don't need to think, work, or even relate to each other? We may become the robots' slaves because that is all we will be capable of after our muscles and brain atrophy.

Sharon Wangness, San Jose, Calif.

SAFETY NOT GUARANTEED

I am skeptical of the proposed colony on Mars ["Bas Lansdorp Has a Posse," November 2014] because the radiation experienced during the mission seems sufficient to cause serious problems, such as radiation sickness. While I applaud the spirit for exploration, one must be sure that the consequences are well understood and the decisions are rational.

Richard S. Stein, Amherst, Mass.

ON THE DEFENSIVE

As an industrial designer who has specialized in heavy equipment, I found the powered exosuits and robotic mule in "The Weight of War" [November 2014] to be fascinating. But why not focus on how little is done to defend our electrical infrastructure, leaving it vulnerable to hackers? It is clear the Pentagon is spending an enormous amount of money on offensive equipment.

Jon Pope, Ridge, N.Y.

We apologize . . . On page 84 of our November issue, we mistakenly affiliated Takanori Shibata with Waseda University. He is a chief senior research scientist at the Human Technology Research Institute at Japan's National Institute of Advanced Industrial Science and Technology.

SHOW & TELL

The creative applications of 3-D printing seem limitless. The machines churn out candy (page 24), costumes (page 68), even cars (page 56). Tell us your favorite 3-D-printed project. Better yet, send a photo: 3d@popsci.com



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Obsolescence is one of the most annoying problems in technology: You save up to buy the newest piece of hardware only to have it eclipsed by a newer, shinier version just a few months later. What if our electronics were built to evolve instead?

That's the thinking behind Boom Boom, a software-upgradable speaker developed by Binauric. The softball-size unit comes with everything you'd expect from a portable speaker system—3.5mm audio input, Bluetooth connectivity, volume and power buttons—plus four microphones, an accelerometer, and a light sensor. Although there aren't many uses for those additional components today, Binauric has issued an app that rolls out upgrades to the speaker. "We don't want to build features without the cooperation of our users," says Binauric co-founder Dettlef Wiese. "We want to see what type of input they give us." For its first major app update, the team released a function enabling spatially accurate audio recordings. "It's too early to name [our next upgrades]," says Wiese, "but there will definitely be new stuff coming." MICHAEL NUÑEZ



Obsessed

Some things are just . . . better

LINDSEY KRATOCHWILL

1 CAMERA51

Filters improve photos only so much. Camera51 helps before the shutter snaps. The Android app analyzes the subject and surroundings, then guides users toward the ideal frame. It will even flag objects that might otherwise ruin a perfect image. **Free**

2 RYOBI PHONE WORKS INFRARED THERMOMETER

Ryobi's new tool plugs into a smartphone's audio jack, allowing it to measure temperatures from -22°F to 662°F—in real time, no less. **\$50**

3 EC LYNC SYSTEM

If there's one thing closets and luggage always need, it's more space. Eagle Creek solved that conundrum with a full-size rolling suitcase that can collapse—frame, wheels, and all—to a fraction of the size. **From \$280**

4 BLADE 98S

Wilson's Blade series is the first set of tennis rackets to incorporate basalt, a natural shock absorber, into the weave and the base. In tests, the Blade gave players better control over the ball, and it filtered and absorbed forces from impact. **\$230**

5 UNCHARTED PLAY PULSE

Socket Ball inventor Uncharted Play has created a jump rope that turns rotational energy into electricity.

Five minutes of jumping powers an LED lamp for an hour. **\$99**

6 "THINGS COME APART"

January means it's time for a fresh perspective. "Things Come Apart," a calendar based on photographer Todd McLellan's book of the same name, shows the inner workings of objects, like telephones and telescopes. **\$15**

7 BUTTERUP

Sure, it's the kind of problem you'd see in a late-night infomercial, but spreading cold butter on toast isn't easy. Struggle no more: Australian industrial design group Design Momentum embedded a grater into a butter knife, turning clumps into thin ribbons. **\$15**

8 RESMED S+

Most sleep trackers are mattress pads or wearable devices, which rely on your movement to tell if you're asleep. They're uncomfortable and can be inaccurate. S+ sits on a bedside table and uses low-frequency radio waves to measure breathing and determine when you're actually sleeping or lying awake. **\$150**

9 EXTREME PRO SDXC UHS-I

SanDisk has created the largest-capacity SD card available. To pack a half-terabyte (512 GB) of memory into an object the size of a postage stamp, SanDisk arranged two vertical 16-die stacks side by side. **\$800**



10 BLACKHAT

In director Michael Mann's latest thriller, the world's cybersecurity lies in the hands of a convicted hacker (Chris Hemsworth). He's part of an international team that tries to stop criminals threatening to undo networks, nuclear reactors, and more. **Jan. 16**



FROM TOP LEFT: COURTESY CAMERA51; COURTESY RYOBI; COURTESY EAGLE CREEK; COURTESY ANDREWS MCMEEL PUBLISHING; COURTESY DESIGN MOMENTUM; COURTESY LEGENDARY PICTURES; COURTESY RESMED; COURTESY UNCHARTED PLAY; COURTESY WILSON; COURTESY SANDISK

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Horsepower 200

Fuel economy 22 miles per gallon overall

Price from \$20,995



Detroit automakers have always dominated the full-size pickup market, but they've more or less ceded the midsize one to Japanese automakers Nissan and Toyota. General Motors plans to reclaim it with all-new versions of the Chevy Colorado and GMC Canyon, which were discontinued in 2012.

Although larger than before, the trucks are still much smaller than

their full-size counterparts. A midsize Colorado with an extended cab is 17 inches shorter and more than 1,000 pounds lighter than a double-cab Silverado. As a result, the trucks are more maneuverable and get better fuel economy by two to five miles per gallon.

The downside is a diminished towing capability, but let's be real: Only a small fraction of potential owners actually need 10,000 pounds of hauling capacity. Most people would probably welcome a more versatile, fuel-efficient truck made right here in the U.S.—and now they have two.



CAR NEWS YOU SHOULD CARE ABOUT

1

Drivers rejoice. The price of crude oil has fallen 20 percent since June, driving down gas prices. The drop is a result of increased U.S. supply without a decrease from other countries. The U.S. produces nearly twice the petroleum it did six years ago.

2

Automakers are exploring noise-canceling technology to replace heavy sound-deadening materials. The system would pipe targeted frequencies through a vehicle's speakers to mute sounds, like the roar of tires against the road.

3

Most of the world's natural rubber comes from one type of plant found almost exclusively in Southeast Asia. Bridgestone and Cooper Tires are investigating a new source native to North America: a shrub called guayule. It could diversify the global supply of rubber.

4

French auto-parts maker Valeo is building an app-supported system that allows vehicles to park autonomously in public garages. Ultrasonic sound-wave sensors, cameras, and lasers attached to the car help it park within just a few inches of objects.

DESIGN OF THE MONTH



Infiniti Q80 Inspiration

Rather than default to the standard luxury-sedan design, Infiniti engineers stretched a sports car to accommodate four doors and a larger interior. The low-slung Inspiration has unique details, such as the retro boat-tail construction of the rear window, making it unlike anything in its class.

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Amount of time the average commuter spends in traffic each year

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REINVENTING THE HOME CEILING FAN

For more than 100 years, ceiling fans remained relatively unchanged. Their motors were inefficient, and their blades didn't move enough air to bring comfort to spaces with tall ceilings and open floor plans. They weren't much to look at, either, but homeowners tolerated them because nothing else was available.

Not anymore. Big Ass Fans has reinvented what a ceiling fan can be with Haiku® with SenseME™ technology. Haiku offers unparalleled efficiency and style, and smart SenseME technology makes it a fan that thinks, learns and makes decisions to keep you comfortable effortlessly.



WHAT'S SO SPECIAL ABOUT THIS FAN?

It's quiet. Silent, in fact. According to POPULAR SCIENCE, it's the world's quietest ceiling fan. Hidden inside that sleek, minimalist exterior is a gearless direct-drive motor that offers efficient, effective performance without making a sound.

It's efficient. Haiku is the top-rated ENERGY STAR® residential ceiling fan, by a long shot—it exceeded requirements for residential fans by 450 percent and costs just \$5 a year to run, thanks to that direct-drive motor.

It's smart. SenseME gives Haiku a brain: It uses an onboard computer and an array of sensors to monitor room conditions and learn your comfort preferences, adjusting the fan speed accordingly. It also features occupancy and motion sensors to turn on and off when people enter and leave a room, cutting down on wasted energy.

It's bright. The optional LED kit is 80% more efficient than incandescent bulbs and has a 50,000 hour lifespan—that's over 17 years of eight-hours-a-day use. The days of standing on a chair to change burnt-out bulbs are over.

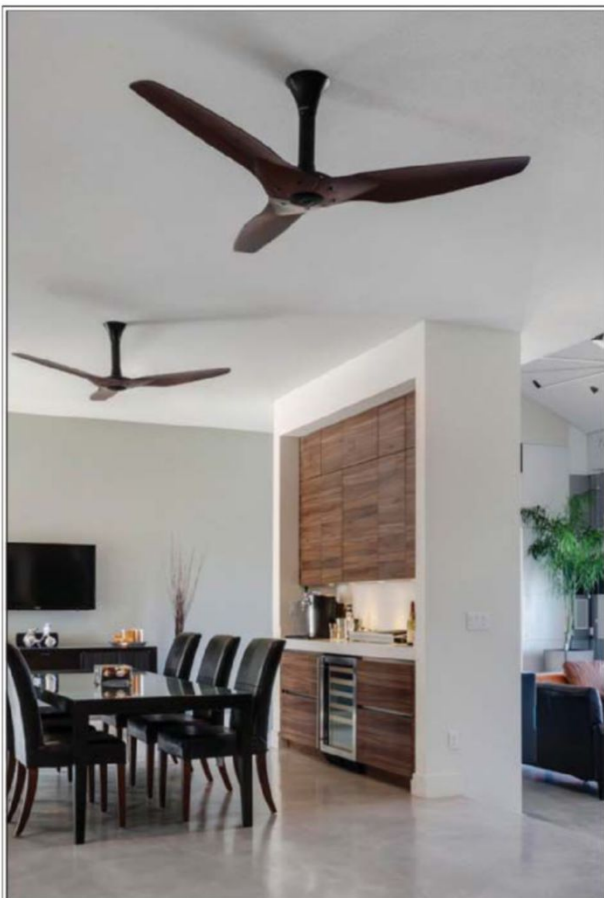
The company's provocative moniker originated with its massive industrial fans, but today **Big Ass Fans** is so much more. If it did things half-ass, you'd still be standing under your ceiling fan pulling a chain. This company goes big ass—and that's precisely why there's **No Equal™**.



Please visit BIGASSFANS.COM for more information



Haiku goes high tech



Haiku® with SenseME™ is the only ceiling fan with an onboard computer. Here's what that means for you:

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- Remembers your preferences to keep you comfortable
- Works with the Nest Learning Thermostat™ to save on energy and bills
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Trending

This Ski Gear Adapts— So You Don't Have To

↓

Skiing isn't a static sport: On any given day, weather can whip from clear and sunny to stormy and overcast, and skiers might toggle between front-country groomers and out-of-bounds powder runs. Companies design gear for every condition, but that makes for a crowded garage. New gear easily readjusts to changing environments, so days on the mountain are more fluid. Plus, you'll have more room to park your car. **BERNE BROUDY**

9.7

Number of active skiers and snowboarders, in millions, in the U.S. 2012–2013 season

1

Uvex Snowstrike VT Goggles

Used by fighter pilots, the technology behind Uvex's variotronic lens can change the goggles' tint in a tenth of a second. A photocell sensor gauges ambient light and sends a signal to the goggles' LCD layer, which is sandwiched between two lenses. The electrical impulse automatically triggers the crystals to turn purple, blue, red, or clear—or the wearer can assume control manually. The Snowstrike works for up to four days on an eight-hour charge. **\$500**

2

Black Diamond Hot Forge Hoody

This jacket is one of the first to use Primaloft's Gold Down Blend, a combination of lightweight, warm down and quick-drying synthetic insulation so enmeshed that the two are indistinguishable under a microscope. To achieve this integration, Primaloft wedged ultrafine synthetic fibers into the spaces between tendrils of gray goose down. This construction props the down clusters open so they can trap air when wet, and dry faster when you work up a sweat. **\$349**

3

Marker Kingpin 13 Binding

Touring bindings let skiers unlock their heels to skin up a mountain and lock in when it's time to rip down. The trouble is, the pins that hold the heel of most touring bindings prevent skis from releasing predictably during falls, causing injuries. Marker's is one of the first touring bindings certified by TÜV, a German standards group, to release reliably. In a wipeout, rollers (not pins) that hold the boot heel in place release, and an underfoot antifriction plate slides out. **\$650**

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The Setup

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2 ASUS PB287Q

This 28-inch 4K UHD monitor displays content at a 3840 x 2160 resolution. **\$649**

3 CORSAIR VENGEANCE K90 RGB

Programmable LEDs beneath the keys give this keyboard 16.8 million possible looks. **\$189**

4 RAZER DEATHADDER CHROMA

Five programmable buttons make this mouse great for fast-paced games. **\$70**

5 ELGATO GAME CAPTURE HD

Flashback Recording allows you to retroactively capture gaming footage. **\$180**

6 FALCON NORTHWEST TIKI

With an optional NVidia GTX Titan Z GPU, this microtower PC is powerful enough to drive multiple 4K displays. **\$1,950**

7 ORIGIN EON17-SLX

This laptop supports dual-graphics cards and an Intel Core i7 quad-core processor. **\$2,008**



During the broadcast of its championship match, *League of Legends*, one of the most played videogames in the world, typically attracts more than 30 million viewers. That audience is more than triple the 8.3 million who tuned in to the MTV Video Music Awards last year. So

it's not surprising that Twitch.tv, the most popular video-streaming platform for gamers, attracts more than 1.2 million broadcasters per month.

With top Twitch personalities earning six-figure salaries via paid subscriptions and ads, many talented videogame players are beginning to consider streaming a viable source of income. But the community is tough to break into. If you're ready to get involved in professional gaming, you'll need the right gear on your desktop. **BRITTANY VINCENT**

61.8

Calories burned by an adult playing sedentary videogames for one hour



The Lightweight Snowblower That Breaks Up Ice

COURTESY BRIGGS & STRATTON

Normally, homeowners must choose between two types of snowblowers: a light, maneuverable single-stage model or a large, powerful two-stage one. The 922EXD combines the best attributes of both. The secret is in the auger. Reinforced rubber-edged paddles wipe concrete clean, and a series of 14 serrated surfaces chop heavier compacted snow. Also, the machine's electric-start engine is guaranteed to work in temperatures as low as -20°F to ensure it boots up in even the coldest blizzards. Now, if we could just get the snowplow to stop barricading our driveways.

LINDSEY KRATOCHWILL

**BRIGGS & STRATTON 922EXD**

Weight
90 pounds
Torque 9 foot-pounds
Engine 205 cc

150

Weight, in pounds, of the lightest two-stage snowblower from Briggs & Stratton

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Tested

PRINT YOUR CANDY AND EAT IT TOO

↓
These days you can 3-D print just about anything—a wrist splint, a figurine that looks just like you, even components for rockets. Now food is on the list. One start-up, Natural Machines, began printing savory meals like ravioli and pizza in the fall of 2013. Over in

Germany, the 13-year-old company Biozoon has started printing easy-to-swallow pureed foods for senior citizens, molded to look like the real thing. And 3D Systems will launch two commercial food printers, the ChefJet and the ChefJet Pro, this year.

That's all well and good, but 3-D-printed food won't have much of a future if it doesn't taste good. So we asked 3D Systems to print out mint and sour-apple-flavored candy for the *Popular Science* staff to try. Like filament printers, the device deposits a powdered-sugar mixture and builds it up layer by layer using a water-based binding agent. The shapes were awesome (geodesic domes!), but what about the taste? **ANDREA SMITH**

100

Number of candies a ChefJet can print in an hour



THE VERDICT

TASTE

"Starts out sweet and ends up sour."

"It's like a Sour Patch Kid meets Pixie Stix, meets a 3-D printer."

"It tastes like an after-dinner mint mixed with a sugar cube. Or a sugar cube made of crushed-up dinner mints."

"I would be very excited if this tasted more like a chip."

TEXTURE

"It's grainy, but I don't mind it."

"It's like a sugar cube mixed with a cloud."

"I've never thought of candy as dry..."

"Gets stuck in your teeth."

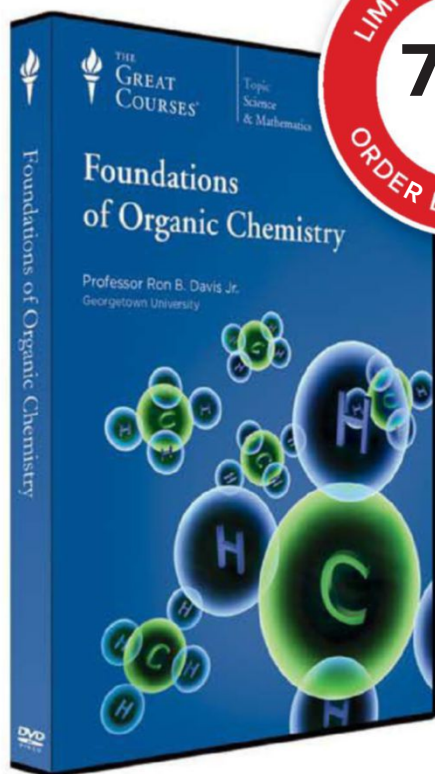
"It's like... what is it like? It's not like anything."

Thread

An intelligent network for the smart home

A Little More Detail:

Thread is a new protocol that allows connected appliances (like lights and thermostats) to communicate wirelessly without a central hub. Because it uses IPv6, the latest version of Internet Protocol, it shouldn't become obsolete anytime soon. It also uses encryption and authentications to ensure security, and it operates at low power. Samsung, ARM, and Nest Labs are involved—hinting that device-to-device communication is the future of the truly smart home. **NEEL V. PATEL**



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As a field, organic chemistry is just a few hundred years old, yet it is already at the heart of modern advances in energy, nanotechnology, and medicine. For all its far-reaching applications, however, organic chemistry is a challenging subject that is feared by many students.

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10K

Number of turns per coil in a standard Les Paul-style pickup.

Pickup

Circuit Board

Switch Control

AFTER 80 YEARS, A NEW RIFF ON THE GUITAR PICKUP

The guitar has changed dramatically since 1931—Chuck Berry happened, Elvis happened, even Guns N' Roses happened. Yet, the component that made this evolution possible, the electric-guitar pickup, has remained largely unchanged.

In August, guitar-electronics company Fishman launched an

entirely new kind of pickup, one that relies on circuit boards. Traditional pickups use coiled copper wire wrapped around poles to create a magnetic field. That field registers disturbances as notes and sends them to an amplifier. The Fluence pickup, on the other hand, uses a sandwich of circuit boards to obtain the same effect. The advantage is that circuit boards, unlike copper wire, are programmable. So while a regular pickup will impart one kind of sound, the Fluence can be programmed to reproduce any number of sounds. **MATT JANCER**

The Components

Circuit Boards

Two 48-layer circuit boards are attached to a separate assembly of poles. Each layer has its own coil. Because all the layers are printed to spec, they're uniform, so the sound is consistent.

Preamp

Every Fluence pickup starts out tonally neutral. A built-in preamplifier shapes sound by subtracting unwanted frequencies to create a sound profile that mimics traditional pickups.

Switch Control

With a push-pull knob, the Fluence can transform the tone of a pickup on the fly. That means users no longer have to choose between a hot-rod and an airy chime tone—the two can be integrated.

Battery

A lithium-ion battery provides up to 250 hours of playtime and recharges via mini USB. Fishman designs its kits to accommodate 9V batteries and other charging systems, which ensures players can fully customize their guitar.

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"After ordering and wearing your Gravity Defyer® [shoes], I have renewed faith that I will be able to continue my passion for senior softball. Thank you." – Ron B

"I work in a restaurant. Finally found the shoes that don't kill my legs and feet...Gravity Defyer® shoes are awesome!" – Diana B

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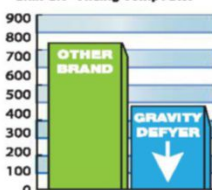
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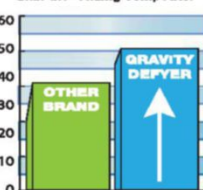
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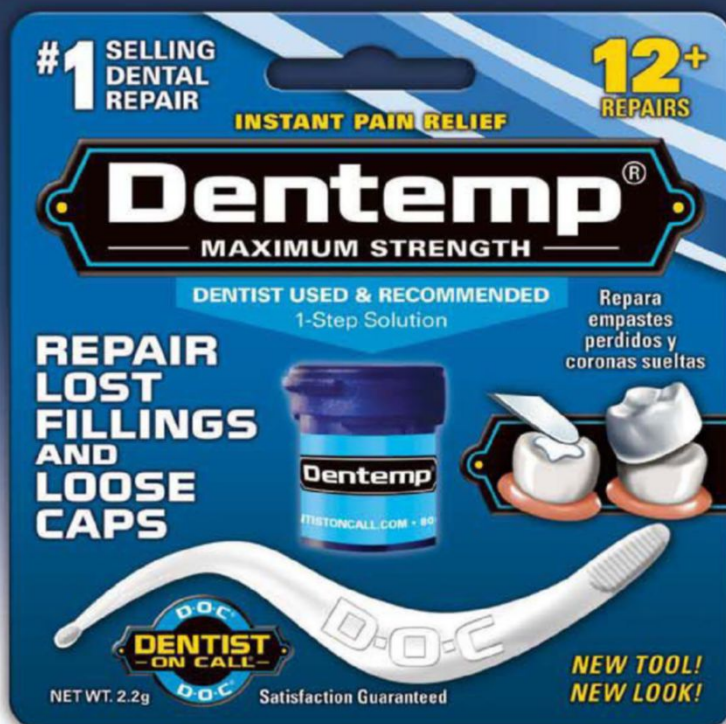
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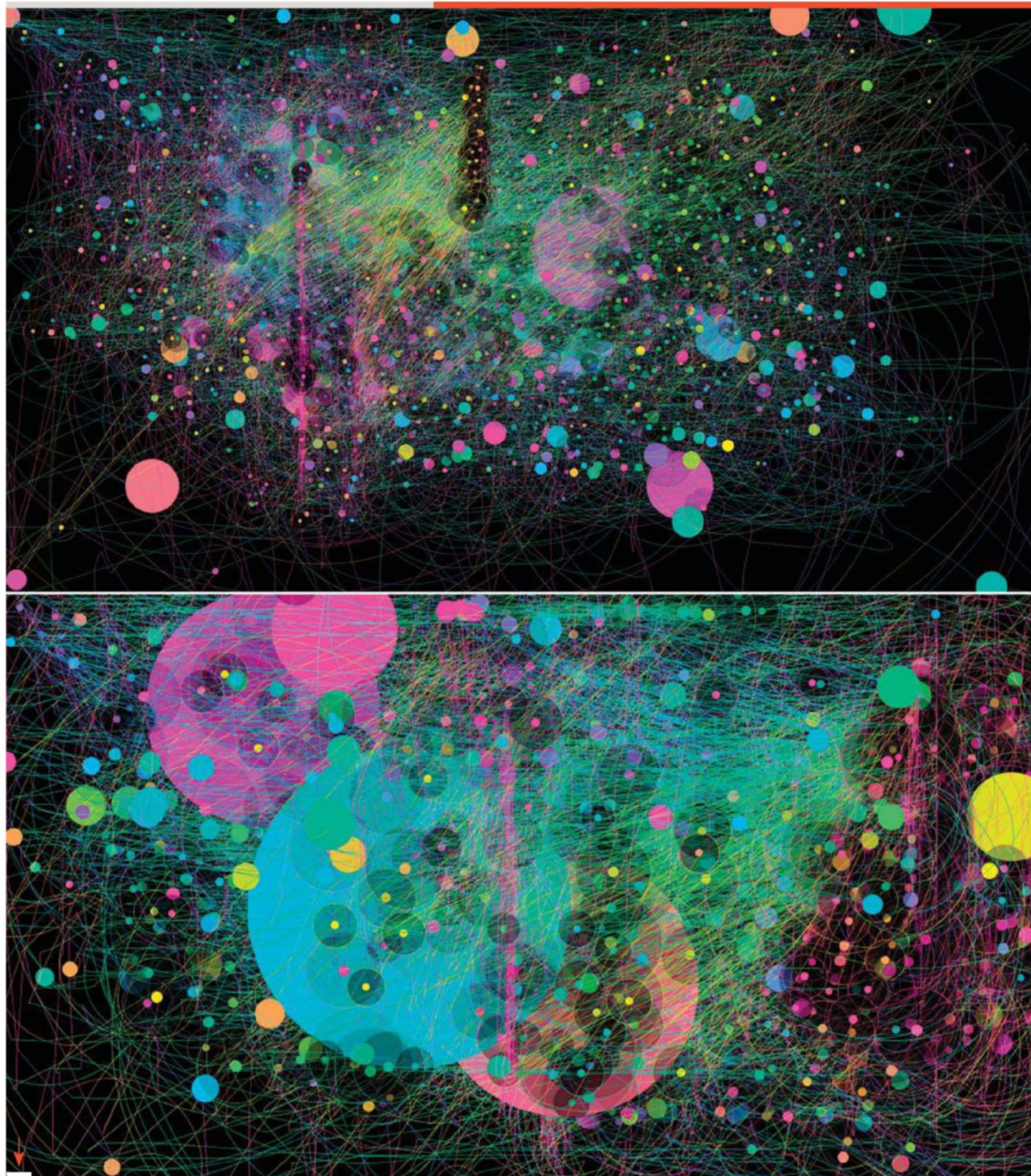
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EDITED BY **Jen Schwartz & Breanna Draxler**



The IOGraph app turns computer-mouse movement (on a *Popular Science* designer's screen [top] and an editor's [bottom]) into art that reflects motion and idling. The prevailing belief is that this kind of intense mousing can compress the median nerve and cause carpal tunnel syndrome (CTS), which affects 3 percent of U.S. working adults. But that connection has been hard to prove. While a February 2014 meta-analysis couldn't establish a causal link between desk-job activity and CTS, a computer simulation from September showed that mouse use can indeed deform the median nerve. So the debate continues.

COLOSSAL SCOPES ON THE HORIZON

↓
Astronomers recently held ground-breakings for three huge telescopes in five months, the first of which should start observations by 2021. The scopes' light-collecting mirrors—each 80 to 126 feet across—will dwarf those at the W.M. Keck Observatory, whose twin 33-foot mirrors are the benchmark today.

With telescopes this large, one challenge is to develop a design that swings easily across the sky and

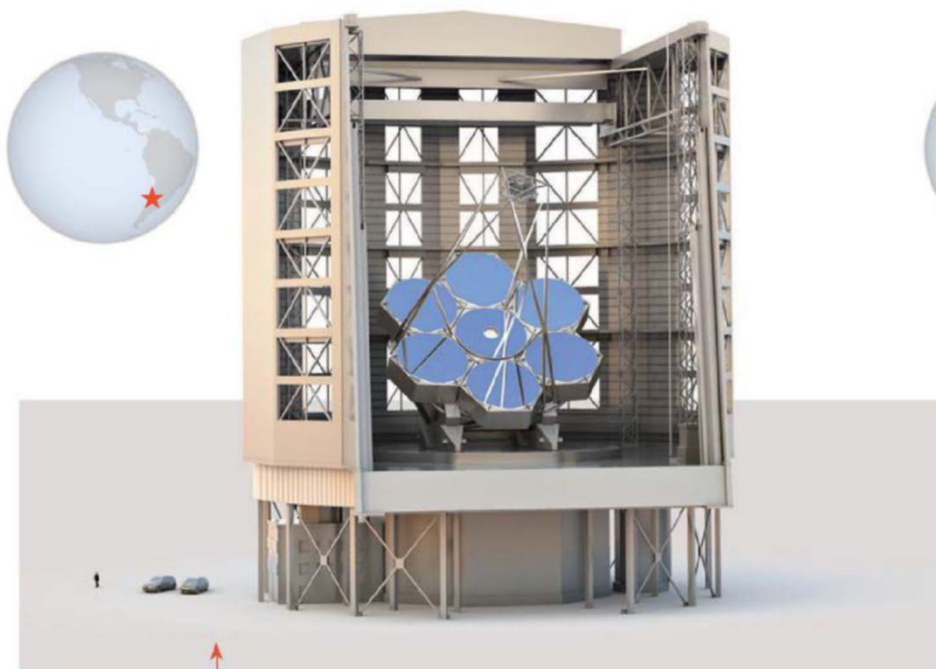
BY **ALEXANDRA OSSOLA**

ILLUSTRATIONS BY **GRAHAM MURDOCH**

minimizes the atmosphere's blurriness. Overcoming these hurdles, engineers have created observatories that will take pictures of the cosmos at resolutions 100 times higher than the current generation of telescopes'. Astronomers will use them to study stars born just after the big bang, detect the expansion of the universe in more detail, and hunt for signs of life on planets around other stars. Even more tantalizing is the prospect of the unknown—the questions astronomers don't yet know to ask but will inevitably stumble upon with new, more powerful tools.

In some ways, three ground-breakings in five months isn't as

surprising as it may seem: Over the past century, design leaps have occurred roughly every 30 years, so this crop is right on schedule. Gary Sanders, project manager for the new Thirty Meter Telescope, explains that three decades is simply the time it takes technology to advance enough to warrant new facilities. Upgraded capabilities come at a price; the observatories will cost more than \$1 billion apiece and likely direct resources away from existing facilities, such as Keck. But Sanders is confident that astronomers will make good use of them. "There are only 365 nights in a year," he says, "and a lot of questions to answer."



Giant Magellan Telescope (GMT)

The GMT's engineers created a novel cylindrical carousel for the telescope's dome. About 40 percent of the structure's surface area is covered in vents. When they open at night-fall, the temperature inside the dome quickly drops to that of the outside air, preventing mismatched temperatures and the distorting turbulent air that comes with them.

Location: Las Campanas, Chile / **Groundbreaking:** November 2014
Expected first light: 2021

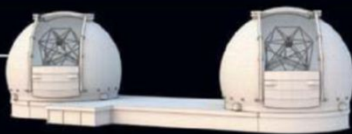


Thirty Meter Telescope (TMT)

Location: Mauna Kea, Hawaii
Groundbreaking: October 2014
Expected first light: 2023

The Gold Standard

W.M. Keck Observatory
Location: Mauna Kea, Hawaii
First light: 1992



When it came online in 1992, Keck was twice the size of the biggest telescopes at the time. So many astronomers wanted to use it that the designers quickly built another nearly identical scope: Keck II, equipped with different instruments, which saw first light in 1996. Since then, the pair has yielded major discoveries, including dark energy, which won a 2011 Nobel Prize.

"With each generation of new telescopes, we open up new things we never anticipated. It's the serendipity that really drives the science."

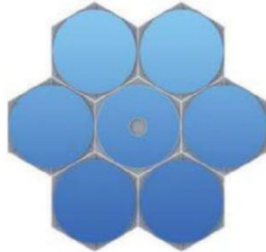
DEBRA ELMEGREEN, astronomy professor at Vassar College and former president of the American Astronomical Society

The Eyes on the Skies

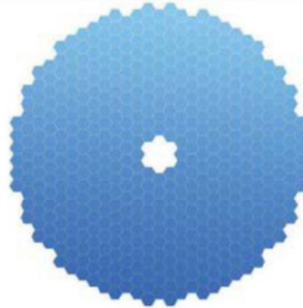
The size of a telescope's primary mirror—the glass that concentrates light from the sky onto the detector—determines its observing power. Bigger mirrors make for finer-detailed images. Here's how the next generation of mirrors stack up against Keck I and II.



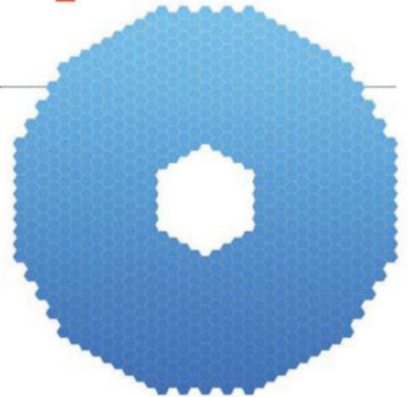
Person
Height: 6 feet



Keck I and II
Diameter: 33 feet

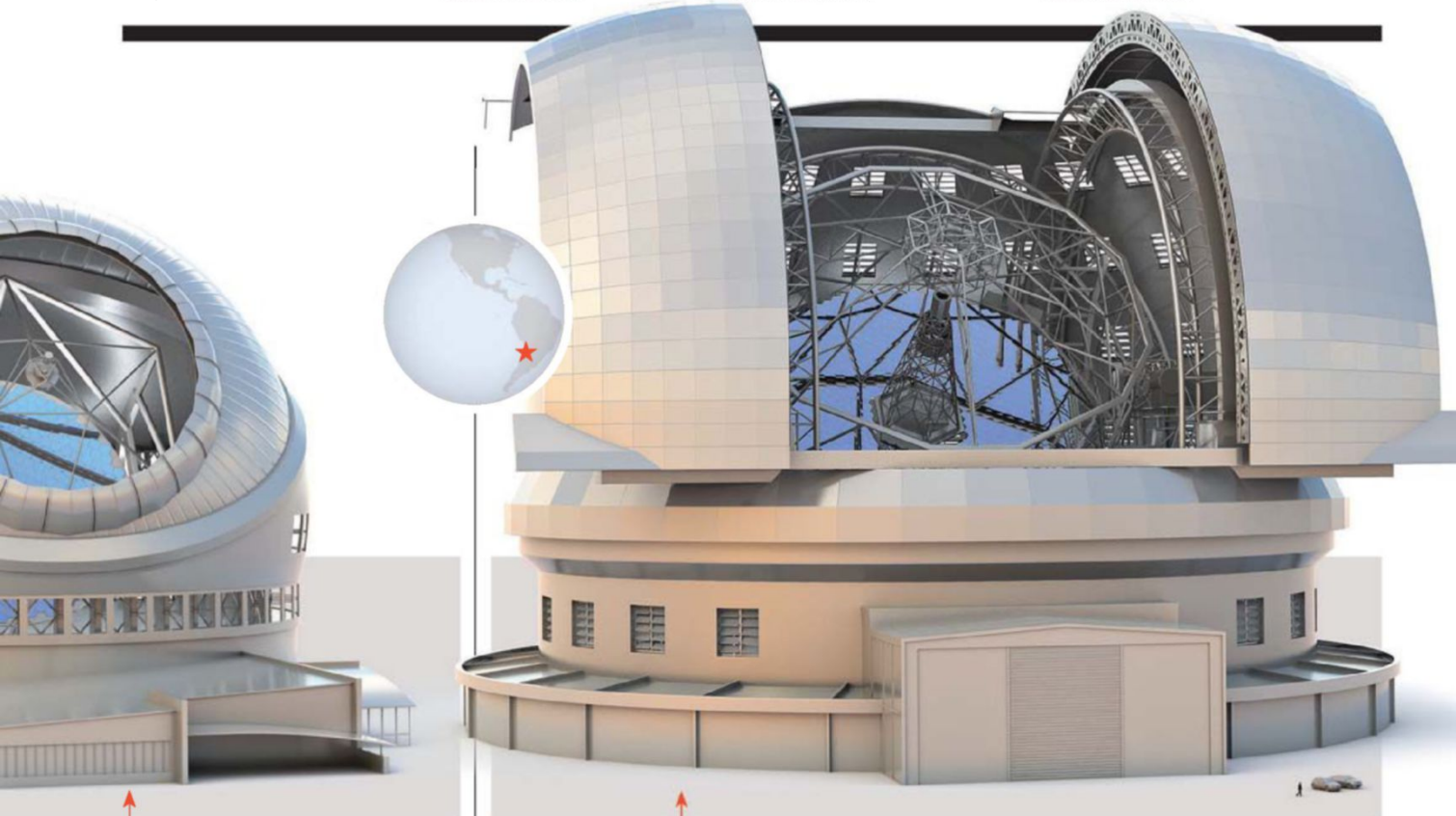


Giant Magellan Telescope
Diameter: 80 feet



Thirty Meter Telescope
Diameter: 98 feet

European Extremely Large Telescope
Diameter: 126 feet



From among three candidate designs, the TMT's planners chose the most unconventional, with a circular opening that's capped with aluminum during the day. The dome will consist of two nested rings that spin independently. The benefit? Speed. It can turn toward a star on the opposite side of the sky in just five minutes.

European Extremely Large Telescope (E-ELT)

The aptly named E-ELT features the most traditional dome design of the three new telescopes. Although shaped like the Keck domes, it's built with 10 times as much steel. A concrete base and thermal insulation will help keep the 8.8 million cubic feet of air inside it cool—essential for clear pictures just after sunset. Even with the insulation, the observatory's air conditioners will require as much electricity as 1,600 homes.

Location: Cerro Amazonas, Chile / **Groundbreaking:** June 2014
Expected first light: 2024

Mirrors That Erase the Atmosphere

Adaptive optics (AO) systems—which compensate for the blurring effects of the atmosphere—were tacked on to the current generation of big telescopes years after they were built. In the new machines, AO is a standard feature. About 800 times per second, actuators adjust the curvature of a mirror in the telescope's light path by a few microns. Luc Simard, the TMT's lead instrumentalist, says AO will allow these observatories to take pictures 10 times clearer than Hubble, whose price tag was four times more than these billion-dollar scopes.

By the Numbers

HOW TO CONVERT CARRY-ONS TO CARBON SAVINGS



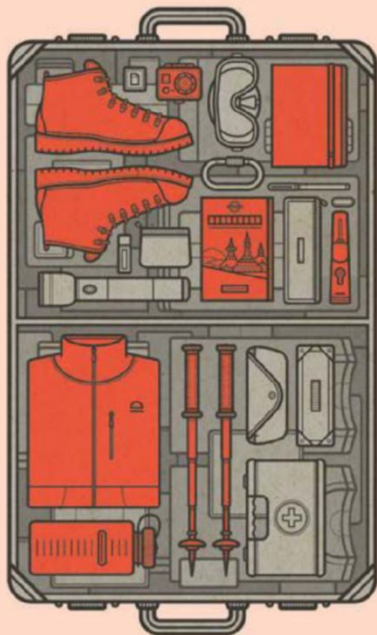
In 2013, American Airlines replaced its pilots' kit bags—35 pounds of paper charts and manuals—with electronic ones stored in iPads. The swap saves at least 400,000 gallons and \$1.2 million of fuel annually. If the 150 or so passengers per flight on a Boeing 737-800 made a similar calculation, the weight reduction would lead to even greater savings and dramatically lower carbon emis-

703

Gallons, in millions, of fuel burned annually on U.S. flights while taxiing. One fix may be towing planes to the runway.

sions. Engineers Brian Yutko and Luke Jensen of MIT's Department of Aeronautics and Astronautics developed an algorithm that shows the relationship between luggage weight and fuel consumption. To slash 1 percent of fuel—and prevent 427 pounds of carbon emissions—the average domestic flight would have to cut 1,750 pounds, or about 11 pounds per person. Here's what that might look like. **HEATHER HANSMAN**

BACKPACKER

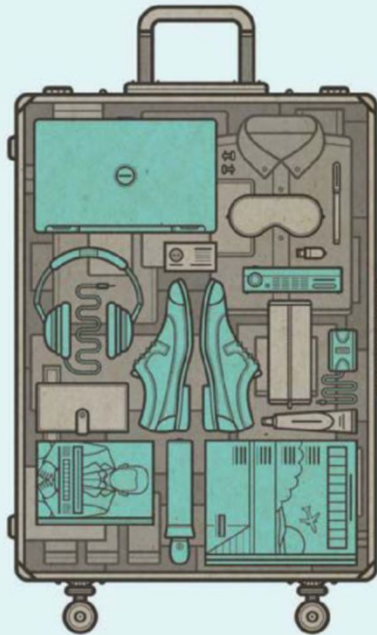


Leather hiking boots **61 oz.**
GoPro camera **3.1 oz.**
Hardcover notebook **14 oz.**
Fleece jacket **26 oz.**
Guidebook **20 oz.**
Full water bottle **38 oz.**
Water purifier **2.9 oz.**
Hiking poles **14 oz.**

TOTAL WEIGHT

11.2 lb.

MOGUL

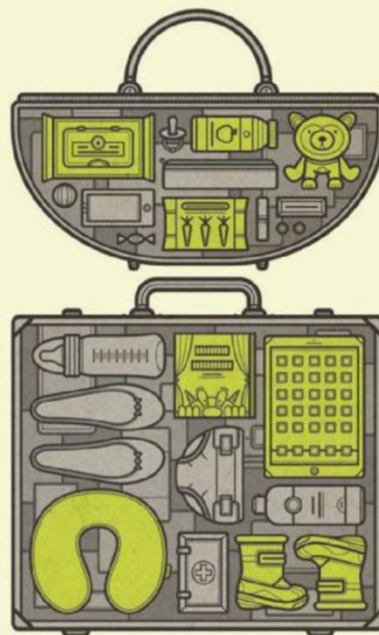


Laptop **70.4 oz.**
Mobile projector **8 oz.**
Headphones **6 oz.**
Undeniable by Bill Nye **16 oz.**
Dress shoes **19 oz.**
Umbrella **10 oz.**
Laptop charger **12 oz.**
Magazine **27 oz.**

TOTAL WEIGHT

10.5 lb.

PARENT



Box of baby wipes **22 oz.**
Tablet **38 oz.**
Baby carrots **20 oz.**
Children's book **21 oz.**
Toddler snow boots **24 oz.**
Bottle of juice **19 oz.**
Neck pillow **12 oz.**
Interactive stuffed animal **24 oz.**

TOTAL WEIGHT

11.3 lb.

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Points of Interest

FOUR WAYS SPACEFARING MICROBES COULD MUCK UP THE SOLAR SYSTEM

To prepare the *Curiosity* rover for its trip to Mars, NASA scrubbed it with alcohol and baked it at 230°F. This is part of the agency's protocol for "planetary protection," a policy devised in the 1950s to keep earthly microbes from contaminating other worlds. But when scientists swabbed *Curiosity* just before takeoff, they found 56,400 organisms from 377 bacterial strains. Then, in the lab, researchers tried to take them out by other means:

ultraviolet blasts, high pH environments, and dehydration. Still, the majority survived at least one trial unscathed. "Whatever we throw at them, they find a way around it," says University of Idaho microbiologist Stephanie Smith. Unless scientists can identify the Achilles' heels of these bugs, missions will keep sending them into space. Here are four ways that could come back to bite us. **SARAH SCOLES**

1

Contagions: During a long stint in a space colony, astronauts' immune systems will likely weaken. If a microbe like *E. coli*—previously found clinging to "clean" spacecraft—contaminates the water or food supply, it could devastate the crew.

2

Invasions: Places with liquid water, such as Europa, might make good bacterial breeding grounds. A hardy species like *Geobacillus stearothermophilus*, prevalent in Earth's ocean sediments and soil, could overrun an entire biosphere once it gets a hold.

3

Mysteries: The organisms that survive NASA's protocols tend to be enigmatic. There are some species, like *Tersicoccus phoenicis*, that we didn't even know existed; scientists have found it only in the clean rooms where spacecraft are assembled.

4

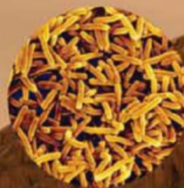
Confusion: If we leave Earth bugs in our wake, any life that planetary scientists may someday detect could simply have fallen off a lander. And without a better understanding of the species we bring to space, we might not recognize it as terrestrial.

TYPES OF BACTERIA FOUND ON *CURIOSITY*



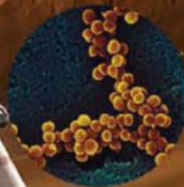
Gracilibacillus

These organisms may eat perchlorates—salts used in rocket fuel that also occur naturally in Martian soil—for breakfast. Enough said.



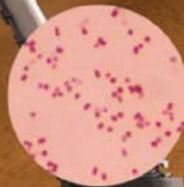
Pseudomonas

Humans can go a few days without water; these bacteria can last weeks. Some species have been found to be resistant to antibiotics such as penicillin.



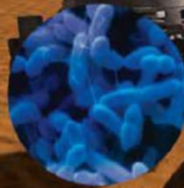
Staphylococcus

Beyond occupying open wounds, colonies of staph can thrive in water more than six times saltier than Earth's oceans.



Moraxella

These bacteria often infect sinuses and lungs. Half the *Curiosity* sample emerged intact from an hour-long bath in hydrogen peroxide.



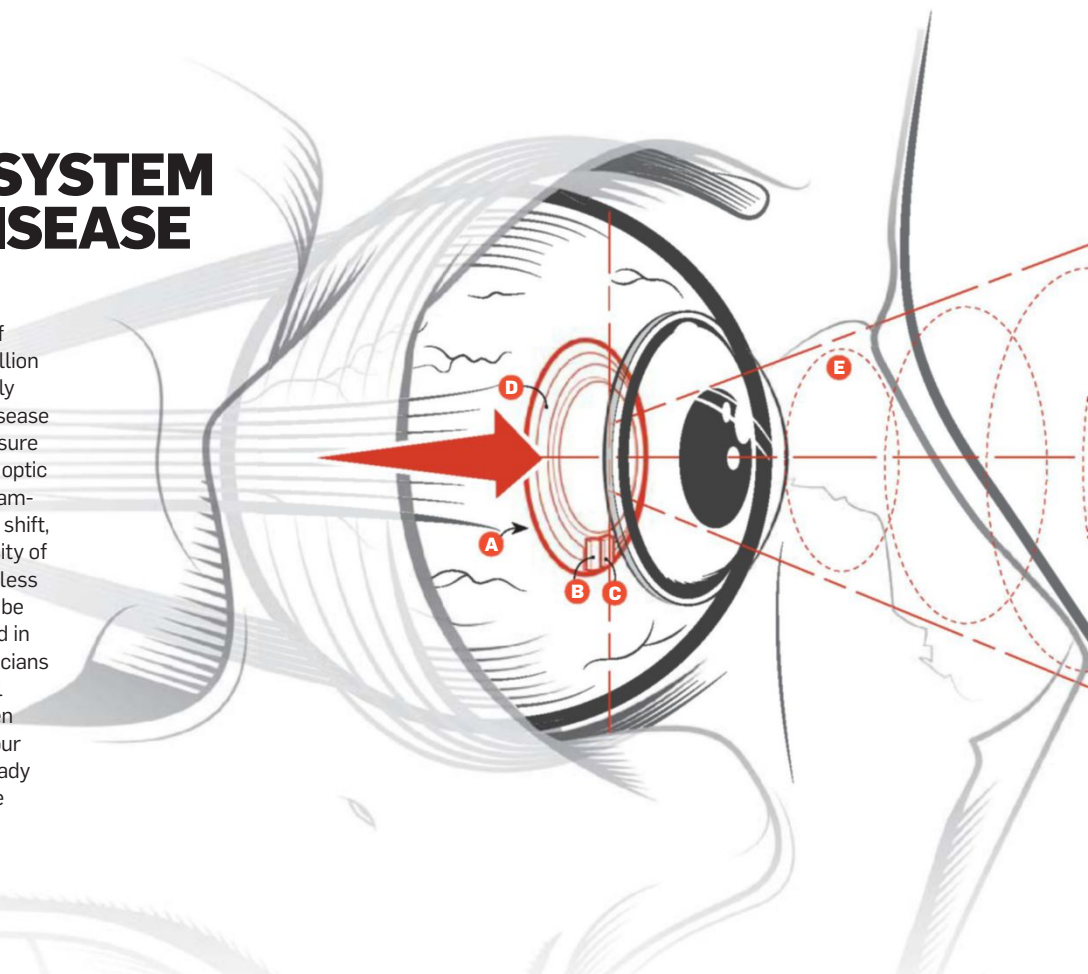
Streptomyces

Strep colonies (not the ones that cause strep throat) can grow in media spiked with sodium hydroxide, e.g., lye, which is normally deadly.



AN EARLY-WARNING SYSTEM FOR EYE DISEASE

↓
Glaucoma is a leading cause of blindness, affecting some 60 million people worldwide. It's also highly treatable, if caught early. The disease typically occurs when fluid pressure inside the eye rises, choking the optic nerve and causing irreparable damage. To detect this often sudden shift, a team of doctors at the University of Washington is developing a wireless sensor small enough that it can be attached to a lens and implanted in the eye. It will send data to clinicians in real time through a peripheral device. (Currently, doctors screen at-risk patients every three to four months.) The system may be ready for human trials in as few as five years. **CORINNE IOZZIO**



How It Works

- A** A silicone replacement lens, similar to the ones used in cataract surgery, contains the device's electronics.
- B** A sensor on a printed circuit board (PCB) continually monitors fluid pressure inside the eye.
- C** A microchip, also located on the PCB, converts pressure data into a radio-frequency signal.
- D** A stabilizing tension ring encircling the device holds the antenna, which acts as both a power receiver and a data transmitter via radio waves.
- E** Data is sent to an external receiver, which will be a dedicated device or a phone peripheral. A doctor will interpret the data and look for pressure spikes.

Seeing Into the Future



Innovega iOptik

Augmented Reality Eyewear

"Anything that produces a display—a phone, a computer, a game driver—can produce that same display in our eyewear," says Jerome Legerton, co-founder of Innovega. The contact lens lets the wearer see within the normal field of vision as well as the up-close media in the glasses. The 60-degree view can even feature 3-D content. Unlike existing video eyewear, iOptik is visible in both eyes; it appears along the top of one's vision, less obtrusively than a baseball cap. It's slated for clinical trials in early 2015.



GoogleX and Alcon Smart Lens

A Lens to Monitor Diabetes

The Smart Lens has a glucose sensor that will measure sugar levels in a person's tears and wirelessly transfer the data to a smartphone, helping some of the 21 million Americans with diabetes better manage the disease. Eventually, it could even provide immediate feedback on the effects of food and exercise. Franck Leveiller, a vice president of R&D at Alcon, says the lens could be on the market in less than a decade. "It's a platform," he says, "so we see it as something that can go far beyond glucose-sensing."

12

Approximate percentage of Americans—37 million people—that wear contact lenses
Source: Contact Lens Spectrum

Why LEDs Are Conquering Lighting

In December, the Nobel Prize for physics went to the team behind a significant invention: the blue light-emitting diode (LED). While red and green LEDs have been around since the 1960s, figuring out how to make blue diodes bright enough stumped engineers until the early nineties. That advance—enabled by high-quality gallium nitride—quickly led to another. By converting blue light to white, engineers produced the crisp beams now ubiquitous in computer screens and smartphones. More recently, they found yet another application: street lamps. To date, Los Angeles has swapped in 155,000 LED fixtures, a move that has reduced both municipal energy bills and light pollution. Ed Ebrahimian, who directs L.A.'s Bureau of Street Lighting, says the benefits are a no-brainer for cities. "We're at the tip of an iceberg," he says. "I think we are going to see a tremendous conversion happening in the next five to 10 years." **ALISSA ZHU**

A CAUTIONARY NOTE
"LEDs have great promise because they're so efficient and highly programmable. The temptation is that we'll crank up the lights brighter because it doesn't cost us anything more. But light pollution can contribute to sleep disorders, which are being tied to major diseases."
PAUL BOGARD, *The End of Night*

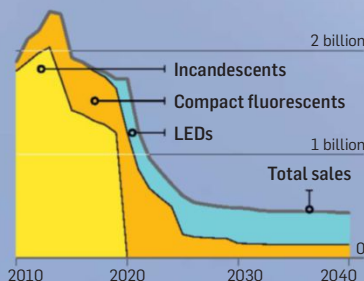
46
 Percentage that U.S. lighting energy consumption is projected to drop by 2030, thanks to the adoption of LEDs—a savings of more than \$30 billion at today's prices
 Source: U.S. Department of Energy

THE COST OF BETTER BULBS

Household LEDs have historically been expensive—in 2010, their average price was almost \$70—which is why they account for just 2.3 percent of today's U.S. bulb market. But that's

changing. Analysts predict prices will plummet to under \$3 by 2025. And with strict efficiency standards taking effect in 2020, experts expect LEDs will find their way into

most homes soon after. Ironically, that could tank the bulb market: LEDs last about 30 times longer than incandescents, so they need to be changed far less frequently. **KATIE PEEK**



CRAVING WARMTH

Sure, incandescent bulbs are wildly inefficient, but nothing signals coziness like their buttery yellow hue. Sora, a company co-founded by Nobel Prize winner Shuji Nakamura, recently developed a method to warm the cool tone of white LEDs by using violet-emitting semiconductors instead of blue ones. Now LEDs can mimic that incandescent charm while slashing energy bills.



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THE YEAR IN IDEAS

Wind/Ebola
Data Trans
Planets/Rel
Orbit/Wate
Robots/Vir
Reality/Dru

Renewable Energy Technologies

In 2015, advances in science and engineering will once again shape the world in profound ways. Here are 10 of the most important.

ILLUSTRATIONS BY MARK MATCHO



No. 01

Wind Power Moves Offshore

When crews begin installing high-voltage cables on Cape Cod, Massachusetts, this year, they'll be laying the foundation for a new era in renewable energy. The power lines will carry electricity from the nation's first offshore wind farm, Cape Wind. Starting in late 2016, its 130 massive turbines will provide a quarter-million New England residents with 75 percent of their electricity—saving them a projected \$7.2 billion over 25 years.

U.S. wind farms currently produce up to 61 gigawatts, but most are located in the center of the country, far from the densely populated coasts. By 2020, proposed offshore projects from Maine to Texas could generate another 3 gigawatts, says energy consultant Bruce Hamilton—enough to power more than two million homes. The U.S. is a full decade behind the United Kingdom and countries like Denmark in terms of offshore wind development, but that may be about to change, Hamilton says. "Cape Wind's success will be a signal to the energy industry: Offshore wind has arrived."

OSHA GRAY DAVIDSON

02

Ebola Drugs Reach West Africa

In December 2013, a toddler in Guinea developed a fever and began vomiting. A few days later, he was dead. His sister, mother, and grandmother soon fell ill and died too. Scientists think these deaths marked the beginning of the deadliest Ebola outbreak on record. As of November 9, 2014, the disease had sickened 14,098 people and killed 5,160, the vast majority in West Africa.

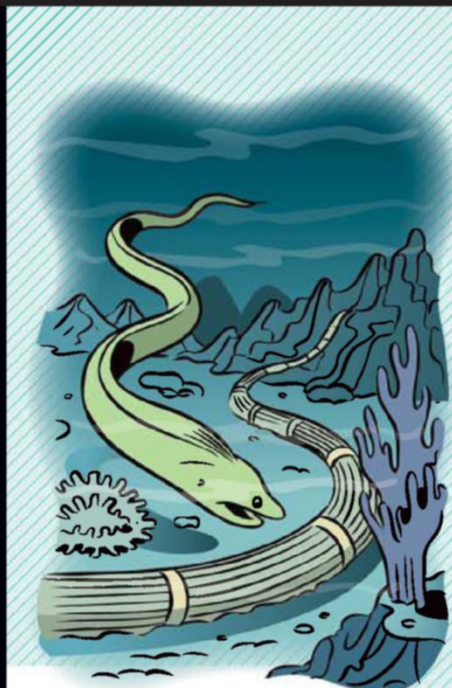
But 2015 may represent a turning point. "The scale of this [epidemic] has driven everybody to move much faster than we've ever seen with the development of a vaccine or the rollout of a drug," says Ian Mackay, a virologist at the University of Queensland in Australia. At press time, researchers were on the verge of launching clinical trials of two leading Ebola-drug candidates—brincidofovir and favipiravir—at treatment centers in West Africa. Marie-Paule Kieny, an assistant director general at the World Health Organization, says two experimental Ebola vaccines

could reach health-care workers in West Africa as soon as January. The one from pharmaceutical giant GlaxoSmithKline relies on a chimpanzee cold pathogen to deliver genetic material from two strains of the Ebola virus. The other, made by Iowa company NewLink Genetics, consists of a livestock pathogen modified to contain an Ebola gene.

With so many lives at stake, a process that normally takes years is being compressed into months. Although incidence in some areas has dropped, "each week we're looking at a rapid expansion of the number of cases," says Peter Hotez, dean of Baylor College of Medicine's National School of Tropical Medicine. There is no guarantee these drugs will work as well in humans as they have in animal models, but the hope is they will be better than nothing, which, until now, was all most patients had. **CASSANDRA WILLYARD**

IN SHORT:

The Ebola outbreak will fast-track the development of medicines and vaccines.



No. 03

Ultrafast Data Transfer Speeds Up Science

When the Large Hadron Collider (LHC) comes back online this spring, it will produce more data than ever before—40 petabytes per year. That surge reflects a trend in science: Increasingly precise instruments produce greater amounts of data.

It's a nice problem to have, but it's still a problem, particularly for scientists based an ocean away from devices like the LHC. Large files that rocket across ultrahigh-speed fiber-optic networks, like the Department of Energy's 100 gigabit-per-second (Gbps) ESnet, bottleneck in slow underwater lines. But by the end of January, ESnet's transatlantic extension will provide 340 Gbps transfer speeds between U.S. and European labs, changing the pace of global collaboration.

"For the hardest problems—not just in physics but in climate science and genomics—there are massive teams working around the world," says ESnet director Greg Bell. "Our job is to make geography irrelevant."

ERIK SOFGE

04 PROBES SOLVE THE MYSTERY OF DWARF PLANETS

IN SHORT:

Scientists don't know what they'll find when probes finally reach Pluto and Ceres, but it's going to be wild.

For the first time, humans are about to explore two new planets in the same year—and not just new planets but new *kinds* of planets. Pluto and Ceres are dwarf planets, meaning they are big and round (like Earth) and share orbits with other objects (unlike Earth). Studies suggest these in-betweeners are key to understanding the formation and evolution of the solar system.

In March, NASA's Dawn spacecraft will begin orbiting Ceres, an anomaly within the asteroid belt. The planet measures about 590 miles across and weighs a third of

all other asteroids in the belt combined. It appears to be a survivor from 4.6 billion years ago, the violent period when the solar system formed. Studies hint that Ceres has clay minerals and frost on the surface, along with a thin atmosphere and perhaps an underground ocean.

Greater revelations await the New Horizons probe when it flies past Pluto in July. At about 1,440 miles wide, Pluto is the largest known member of the Kuiper Belt, an enormous zone of frozen bodies that extends far beyond Neptune. Over the years, we've learned a few

basic details: Pluto has five known moons, and one is more than half its size. It rotates sideways and experiences extreme weather: In summer, the surface ice evaporates into an atmosphere, which then freezes back onto the ground each winter. Wild temperature swings may also trigger icy eruptions.

But mostly, we don't know what to expect. As New Horizons sails into the Kuiper Belt, it ventures into unexplored territory. In the words of mission scientist Alan Stern, "Nothing quite like this has happened in decades." **COREY S. POWELL**

January

Energy

Components begin arriving for Iter, the multibillion-dollar international fusion project conceived 30 years ago. The site in southern France will host the largest thermonuclear reactor ever built.

February

Technology

The first commercial robot to read and respond to human emotions will go on sale for about \$1,700. It uses artificial intelligence to recognize facial expressions and learn from past experiences.

March

Astronomy

Residents of Iceland, Europe, North Africa, and North Asia can witness a partial solar eclipse. A total eclipse will be visible in the North Atlantic, the Faroe Islands, and Norway.

05

Over the course of four Thursdays in November 1915, Albert Einstein stood before the Prussian Academy in Berlin and unveiled a set of equations that upended our ideas about space and time. A century later, his grand project remains frustratingly incomplete. Sure, the general theory of relativity has become the foundation of our modern understanding of the big bang, black holes, and gravity itself—but crucial parts of it remain unverified.

One unproved prediction is that an accelerating mass should create gravitational waves, like the ripples from a boat sailing across the surface of a lake. In July, the hunt for those waves will heat up with the launch of a detector called Lisa Pathfinder, which will test technology for a new gravitational wave observatory in space. Starting in 2015, two earthbound experiments, Advanced Ligo and Advanced Virgo, will be brought online. They should be able to pick up gravitational disturbances from exploding stars. Another test will examine the motions of a triple-star system called PSR J0337+1715 to check if gravity behaves the same toward all kinds of matter, as Einstein believed.

Some scientists suspect other aspects of relativity are just flat-out wrong. For years, cosmologists have observed dramatic, unexplained movements of galaxies. Those motions are normally attributed to hypothetical dark matter and dark energy, but at a series of

GENERAL RELATIVITY GETS PUT TO THE TEST

May

June

July

September

Engineering

Dublin will be blanketed with a network of sensors. The devices, developed by Intel, will track air quality, noise levels, and other data. The city also plans to use them as a platform for apps.

Robotics

First-responder robots will crawl and cut their way through a simulated disaster zone in the finals of the DARPA Robotics Challenge. The victorious team will win a \$2 million prize.

Exploration

The New Horizons probe will fly by Pluto on the 14th, completing U.S. reconnaissance of the solar system. It will take photos that show surface features as small as 200 feet across.

Aviation

Congress has mandated the Federal Aviation Administration to safely integrate drones into U.S. airspace by month's end. The rules will be informed by data from test sites in six states.

**IN
SHORT:**

We're sure Einstein was brilliant, but scientists are still trying to figure out whether he nailed his most famous theory.

GENERAL RELATIVITY

TO THE

conferences this year, physicists will explore the possibility that gravity simply doesn't work the way Einstein thought. And then there's the elephant in the lab: General relativity clashes with quantum mechanics. Attempts to reconcile them have so far yielded nothing

but endless, inconclusive papers about string theory.

Physicists' greatest hope for 2015, then, is that one of these experiments will show where Einstein got off track, so someone else can jump in and get closer to his long-sought "theory of everything." **C.S.P.**

No. 06

Commercial Space Habitats Go for Launch

In 2014, commercial spaceflight reached a major milestone when NASA selected two companies—SpaceX and Boeing—to deliver astronauts to the International Space Station (ISS). This year, the agency will turn its attention to the next logical step: commercial habitats.

SpaceX will launch Bigelow Aerospace's Expandable Activity Module to the ISS in late summer or early fall. Once connected to the Tranquility node, the habitat will inflate to 13 feet

long. Then, for two years, instruments will measure how well it holds up in space. Bigelow will use that data to build a 12-person station.

NASA, meanwhile, has begun developing standards for use by commercial stations. Philip McAlister, the agency's director of commercial spaceflight, says private enterprise will help sustain robust human activity in low-Earth orbit. "American spaceflight is not just about us anymore," he says. **LOREN GRUSH**



Western States Face the Water Crisis

07

For the third year in a row, California has suffered severe drought. Reservoirs hit all-time lows, wildfires raced through dry forests, and some towns ran out of water.

Many Central Valley farmers, desperate to irrigate their crops, made heavy withdrawals from their water "savings accounts"—the groundwater beneath their land. But that's a short-term fix at best, and it has serious consequences: In recent years, some areas have subsided more than 100 feet.

On September 16, 2014, California Governor Jerry Brown signed three bills designed to strengthen groundwater regulation. While they don't require sustainable withdrawals for two decades, they do call for a more precise accounting of the underground resource. "Right now, we don't even know how much money is in the bank," says hydrologist Jay Famiglietti, of the University of Cali-

fornia at Irvine. "We just know the balance is getting lower and lower."

New techniques for measuring water near and on the surface will add resolution to that picture in 2015. Researchers from the Scripps Institution of Oceanography found that tiny uplifts in the Earth's crust reveal the amount of water lost throughout the West. Another team, led by the University of Colorado at Boulder, developed a way to use GPS instruments to gauge soil moisture and snow depth.

Knowing how much water states have to work with won't put them in the clear. Climate change inevitably leads to more drought. But data will awaken Westerners to the crisis at hand—and point the way toward mitigating it. **MICHELLE NIJHUIS**

IN SHORT:

New data will reveal the actual scale of groundwater resources.



No. 08

Robots Join the Open-Source Revolution

Three of the most sophisticated robots ever built—NASA's Robonaut 2, Rethink Robotics' Baxter, and Boston Dynamics' Atlas—have one thing in common: They all run on the Robotics Operating System (ROS), open-source software that's rapidly becoming the Android of robotics.

Why is this significant? Because ROS is the Platonic ideal of the open-source movement: powerful, free code that cooperates rather than competes with other platforms. And it's showing up everywhere, including R&D labs at Boeing and Ford. "We've achieved a critical mass in robotics that's unmatched," says Open Source Robotics Foundation CEO Brian Gerkey.

The number of downloads doubled in 2014, to 3.5 million, and Gerkey expects adoption to spike again with the release of ROS 2.0 this summer. The upgrade will coordinate swarms, improve walking, and support smart sensors—basically, assimilate the world's robots. **E.S.**

November

December

Metrology

The international panel that keeps track of the world's time scale is expected to reach consensus on whether to abolish the leap second. If they do, time will slowly decouple from Earth's rotation.

Climate

The United Nations will once again try to negotiate a universal agreement on climate change—one with collective cuts to greenhouse-gas emissions sufficient to keep warming below 2°C.

09 VIRTUAL REALITY MEETS ITS PUBLIC

IN SHORT:

A handful of VR devices now in development will soon make their way to consumers.

In the first virtual reality (VR) boom in the 1990s, there were few bigger fans than Jeffrey Travis. The engineer and filmmaker had been waiting for the day he could don a virtual jetpack and explore a virtual world. Then he actually tried VR. “It was lame,” he says. “The graphics were so bad it was impossible to tell what you were looking at.” Fast forward to 2015, when Travis will introduce his own VR product: a hyper-real jetpack ride called Rocket Ace. The user, wearing an Oculus Rift headset, will step into a nylon harness and “fly” Superman-style.

With the purchase of Oculus VR in 2014, Facebook effectively ushered in an era many knew was rapidly approaching. “There’s been a convergence of high-resolution small displays, improved motion-detection sensors, and Moore’s law,” Travis says. Other companies also took action. Samsung teamed up with Oculus VR to develop a headset for the Galaxy Note 4, and Sony debuted Project Morpheus, a prototype headset for the PlayStation 4. Google sold development kits that will allow its Project Tango, a phone with a suite of sensors and

computer vision, to be used as a VR platform. And Microsoft offered a glimpse of RoomAlive, a proof-of-concept that uses projectors and the Kinect system to transform any room into augmented reality.

That the titans of technology are piling into the VR space only bodes well for consumers. Existing supply chains will help turn today’s development kits into slick products with, ultimately, lower costs. So while 2015 won’t be the year that every American buys a VR headset, it will be the year we all start to want one. **ANDREW ROSENBLUM**

No. 10

Biosimilars Hit the U.S. Market

Most drugs are designed by chemists, but some of the most promising ones for diseases like cancer, arthritis, and multiple sclerosis are made by living cells. These medicines, called biologics, can be pricey: A full course of the breast-cancer drug Herceptin costs \$50,000. Biotech companies can’t produce exact replicas of biologics, but they can come close. Cheaper knockoffs, called biosimilars, are on the way.

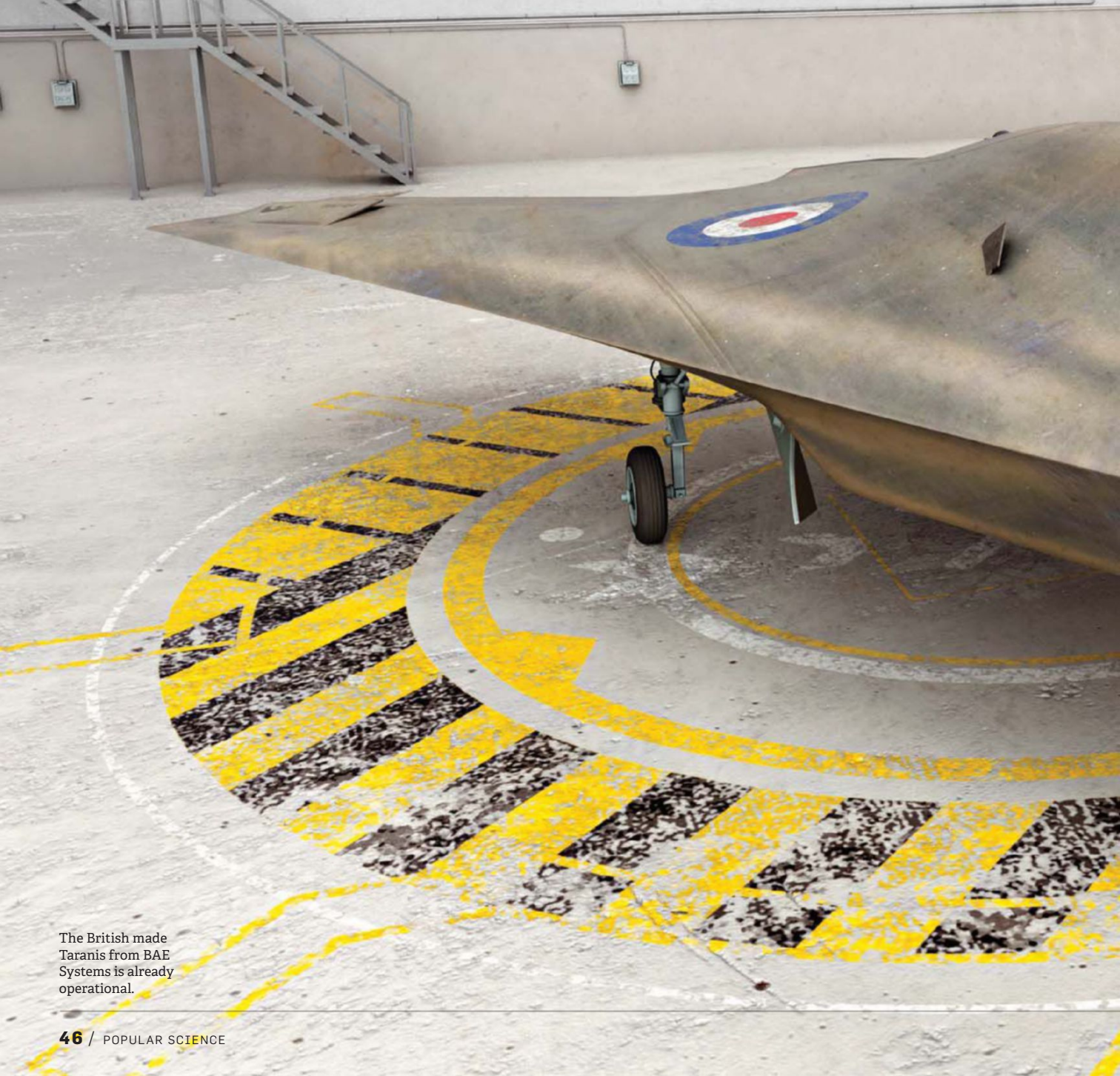
Because biosimilars differ slightly from the molecules they mimic (unlike generic drugs), they’re tougher to regulate. The Food and Drug Administration recently outlined a path for approval, and last summer, two companies filed applications. Thomson Reuters analyst Mari Serebrov predicts a green light in 2015, paving the way for more copycats—along with big savings for patients and insurance companies. **C.W.**



INSIDE THE NEW STEALTH ARSENAL

A top secret class of autonomous drones is changing the way war is waged.

By Eric Adams



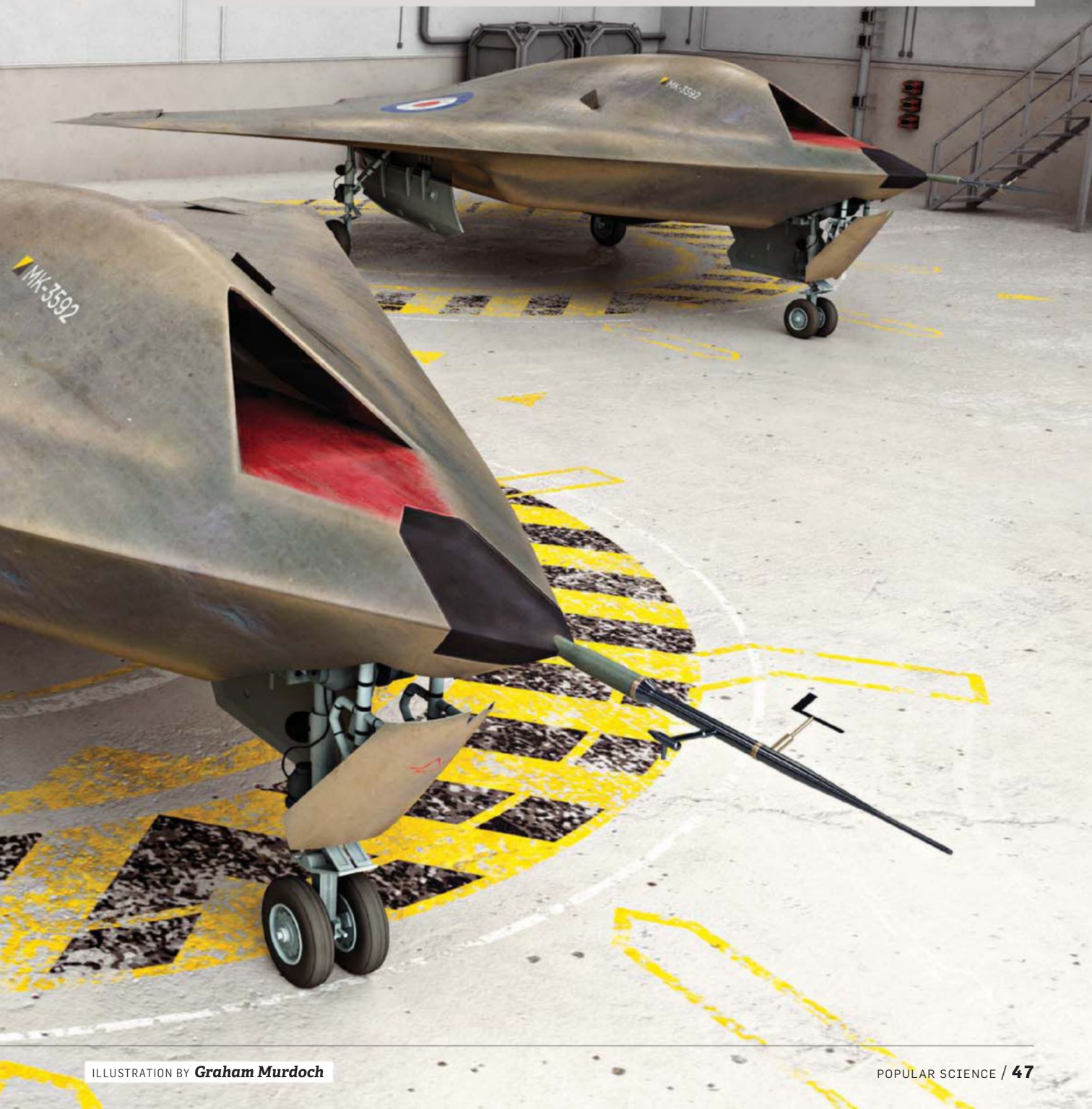
The British made Taranis from BAE Systems is already operational.



On May 2, 2011, an unmanned aerial vehicle (UAV)—locked in a steady, predawn orbit above a residential compound in Abbottabad, Pakistan—transmitted live video of an unfolding military raid to a laptop in the White House Situation Room. There, President Barack Obama and his national security advisers watched as a team of Navy SEALs infiltrated the walled compound and killed its chief resident, Osama bin Laden.

By almost any account, the mission was a tremendous success, but an elemental part of the victory has gone all but unnoticed. The operation might never have happened were it not for a new aircraft, the Lockheed Martin RQ-170 Sentinel, which had been monitoring the location for months.

The aircraft's mere presence over Pakistan was notable. Abbottabad is home to the country's



military academy and close to nuclear-weapons production sites and other sensitive facilities. The Pakistani government is especially vigilant about UAV activity nearby, whether it's to deter Indian spies or unruly American allies. Suffice it to say, when Bin Laden was house hunting, "sheltered under an umbrella of radar protection" likely sat high on his wish list. Compared with neighboring Afghanistan, where Predator and Global Hawk reconnaissance craft roamed the skies, Abbottabad must have seemed a safe haven.

But Bin Laden never knew about the RQ-170. The top secret, remotely piloted aircraft, which arrived in Abbottabad as the search for the Al Qaeda leader intensified, was the first operational UAV able to conceal its own presence. The craft's shape was designed to scatter radar waves, and other tactics helped mask its signature. It was considered only moderately stealthy, but it was still good enough to slip in and out of Pakistani airspace and capture video of Bin Laden pacing in his garden. That feat delivered more than a big break in a decade-long manhunt: It allowed a brief but revealing glimpse into the future of warfare.

NEW WARS, NEW CRAFTS

Since the September 11 attacks, the U.S. has been embroiled in a number of conflicts—directly in Iraq and Afghanistan, but also in shadow wars in Somalia and Yemen. Although each conflict is unique, all share a common and rather unusual characteristic: an asymmetric distribution of power, where one combatant has many more resources than another. In such situations, UAVs are ideal; they can be flown at will because the adversary has no means to shoot them down.

As military strategists look ahead, the days of asymmetric warfare and the uncontested airspace that comes with it seem to be drawing to a close.

"There are no active area defenses run by insurgents in Afghanistan and Iraq or, for that matter, Syria," says defense analyst Phil Finnegan, of the Fairfax, Virginia-based Teal Group.

"But the next generation of UAVs will have to confront potential threats like China. They'll need to be much more capable—faster, with greater autonomy in case communication links are disrupted, and stealthier so they are more difficult for an adversary to detect."

The RQ-170 was the first evidence of such a program, but it was only the opening salvo. Engineers have



"THE NEXT GENERATION OF UAVS WILL HAVE TO CONFRONT POTENTIAL THREATS LIKE CHINA. THEY'LL NEED TO BE MUCH MORE CAPABLE."

WE FLEW TWO SECRET STEALTH DRONES. HERE'S WHAT WE LEARNED.

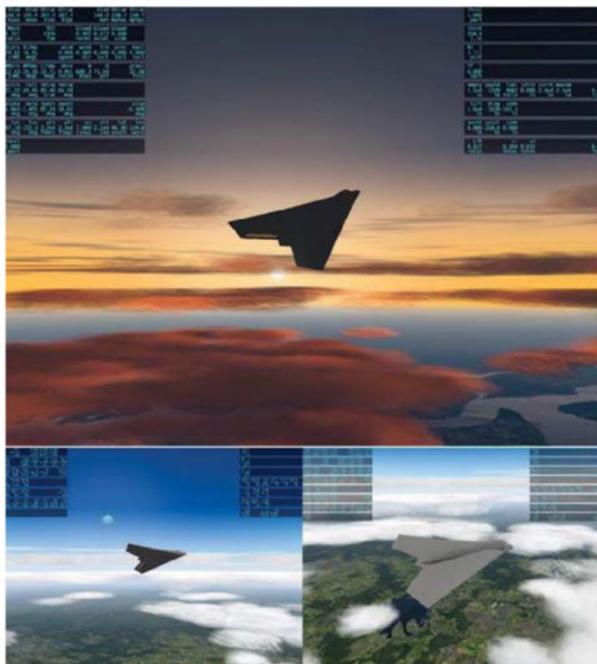
The Challenge

The Taranis and the RQ-180 are classified projects. The RQ-180 is so "black-world" that it's been spotted only once or twice, flying high over the U.S. Air Force's remote Area 51 in Nevada. But information on both UAVs has leaked, and in the right hands it can speak volumes about their capabilities. To that end, *Popular Science* recruited Austin Meyer, aeronautical engineer and creator of the benchmark flight simulator X-Plane, to build true-to-life virtual models of the Taranis and RQ-180 and flight-test them with his software. The experiment granted the most detailed look ever at this new class of stealth UAVs.

The Tests

Popular Science scoured the scant records available for details on each aircraft—wingspan, fuselage length, engine power—and examined the handful of images that have been leaked to the public. Meyer then used the intelligence to build and sculpt digital versions of the UAVs and fly them in the X-Plane simulator. He adjusted landing-gear placement, wing thickness, and a number of angles and arcs. Then he estimated flight characteristics and performance based on the overall configuration. "The shape of an airplane tells you what it can do, if you just know how to listen," Meyer says.

Want to fly these planes yourself? To pilot both aircraft—and many other simulations—head to popsci.com/xplanesim for instructions and links to the downloads.



The Results: Taranis

On its first flight, the Taranis lifted off from the runway, flopped onto its back, and crashed in a huge virtual fireball. For the next attempt, Meyer nudged the center of gravity forward. That helped, but only so much. If you push the narrow, flying-wing design too far, it spins out of control; the craft requires full-time computerized supervision to stay airborne. The Taranis has no vertical stabilizer, so it presumably uses speed brakes for yaw control (steering left and right). "Usually, flying wings can steer by adjusting throttles from one engine to the next," Meyer says. "Taranis has just one engine, so speed brakes create drag, pulling one wing behind and sending the other forward."



Estimated Specifications

WINGSPAN

33 feet

LENGTH

41 feet

FLIGHT TIME

Up to 6 hours

TOP SPEED

700+ mph

STEALTH

● ● ● ● ●

MANEUVERABILITY

● ● ● ● ●



The Results: RQ-180

The maiden flight of our RQ-180 model couldn't have been more different: It revealed the real craft's aerodynamic elegance. "It's graceful and easy to fly, which indicates how sophisticated the aerodynamics are," Meyers says. "It's basically an engineer's dream." Like a glider, the plane is exceptionally lightweight—airplanes with wings that large tend to be heavier—and as a result, the model seemed to fly higher (60,000 feet or more) than current estimates. Because it's so efficient at high altitude, the model's fuel-consumption rate was low, suggesting it can fly farther on a single fuel load—across continents and for more than seven hours.



Estimated Specifications

WINGSPAN

130 feet

LENGTH

50 feet

FLIGHT TIME

More than 7 hours

TOP SPEED

600+ mph

STEALTH

● ● ● ● ●

MANEUVERABILITY

● ● ● ● ●

The New Stealth Arsenal

already developed two new craft, Northrop Grumman's RQ-180, now in tests at the military's covert Area 51, and BAE Systems' Taranis, which is geared more toward combat than surveillance. Both feature unprecedented levels of stealth for a UAV, and both are equipped with some form of autonomy, though the details remain a closely guarded secret.

As the pendulum of war swings back toward symmetrical conflicts, whether in Eastern Europe or the Pacific Rim, the designs of such craft are powerful indicators that military planners see UAVs serving a critical role. The challenge is to build them in such a way that they'll function on their own without anybody ever knowing they're there.

THE DISAPPEARING DRONE

At the height of the Cold War, Lockheed Martin developed the F-117 Nighthawk, the world's first operational stealth airplane. To pilots, the gangly, heavily faceted, pitch-black aircraft appeared to abandon sound aerodynamics. The flat, radar-deflecting surfaces, they argued, would make the jet nearly impossible to fly. (They were right: It was safely piloted only with the aid of advanced, persistent fly-by-wire computer intervention.) Regardless, the design rendered it essentially invisible. On radar, the F-117 appeared no bigger than a duck.

As computing systems advanced, engineers could improve models' stealth characteristics, and the Nighthawk's awkward design fell by the wayside. Stealth airplanes, like the F-35 Lightning II fighter and the F-22 Raptor (the size of a marble on radar), began to more closely resemble conventional aircraft.

The RQ-180 and Taranis are perhaps the best examples of stealth applied to a UAV. Both use a flying-wing design also seen in the manned B-2 Spirit stealth bomber and the Navy's X-47B UAV, currently in flight tests on aircraft carriers. Since there are no vertical stabilizers or bulky fuselage, radar reflects off fewer surfaces, masking the UAV's signature. Of course, without those features the configuration is inherently unstable, so the craft have to adjust continuously via wing-mounted control surfaces.

In terms of stealth, the RQ-180, which first came to light in December 2013, has a distinct advantage: The wingspan stretches 130 feet. (RQ-170 has only a 65-foot span.) That width, plus finely tuned aerodynamics, not only lets the aircraft fly higher (60,000 feet) and longer than the RQ-170's roughly six-hour limit, but it also allows engineers to place control surfaces farther out on the wing, where smaller adjustments are required to move the plane. This, in turn, means that the control surfaces can be much smaller, so they won't catch radar.

The Taranis, on the other hand, has a modest 33-foot wingspan. That limits its range and altitude capability and requires larger stabilization panels (along with, presumably, a flight-control protocol to limit panel movement at certain stages of a mission). But it also makes the Taranis much more nimble than the RQ-180.



The craft seems geared to low altitude and high speed.

In a recent paper published in *The Aeronautical Journal*, BAE Systems engineer Chris Lee described how the team developed an entirely new data-gathering-and-analysis system to hone the Taranis's stealth characteristics during flight testing. The engine inlet and exhaust were given particularly careful attention. Shaping them to conceal the engine—which can quickly betray airplanes to radar—disrupts airflow, so engineers had to relentlessly tweak the engine design. Stealth is a game of give and take, and engineers are often forced to choose between performance and concealment.

The Taranis and the RQ-180 point to where UAVs are headed. Capable of flying more than 700 miles per hour, the Taranis has the speed and maneuverability to confront threats in combat head-on. The RQ-180 will pick up where the most famous spy plane, the SR-71 Blackbird, left off when it ceased operation in 1998. "The RQ-180 is a major step toward combining endurance and survivability in a high-end UAV," says Loren Thompson, chief military analyst at the Lexington Institute. "In addition to performing reconnaissance missions, it will have some capacity to execute electronic attacks against enemy sensors and networks. I expect it will be used mainly in areas where the appearance of double-digit SAMs [surface-to-air missiles] and integrated air defenses have made the penetrability of nonstealthy airframes problematic."

Translation: It won't get shot down.

PILOT-FREE WARFARE

In July 2013, the Navy's X-47B approached the bucking, heaving deck of the USS *George H.W. Bush* aircraft carrier for a landing. Unlike remotely piloted drones, the X-47B had no human at the controls. Instead, it carried a sophisticated autonomous software package that guided it onto the flight deck entirely unassisted.

The X-47B's demonstration simply confirmed what



From left:

The MQ-9 Reaper, the classic standby; the SR72, a hypersonic unmanned craft; the RQ4 Global Hawk, a high-altitude endurance plane; the Taranis



STEALTH IS A GAME OF GIVE AND TAKE, AND ENGINEERS ARE OFTEN FORCED TO CHOOSE BETWEEN PERFORMANCE AND CONCEALMENT.



most aircraft engineers have known for a long time: Aircraft will become progressively more autonomous. Although it's not stealthy, the Global Hawk UAV has significant autonomy—for years, it has navigated crowded airspaces and airports and flown in the same combat theaters as manned airplanes.

No one outside the military knows the exact nature of the autonomy packages of the RQ-180 and the Taranis, but they are almost assuredly the most sophisticated to date. Autonomy in aircraft is actually the “easiest” version of robotic self-control, since there are few obstacles in the open sky and considerable room to correct an error. (This is a sharp distinction from autonomous ground vehicles, which are years behind unmanned aircraft.) A suite of sensors, including radar, GPS, inertial navigation, and conventional autopilot functions, keep the airplanes in flight and in line with mission waypoints and goals, permitting them to collect data, send communications, and, in certain cases, drop bombs and launch missiles.

That said, it's a fallacy to assume that robots will dominate all future combat. As many in the military see it, UAVs are force multipliers, not pilot replacements. “We're never going to get to a point where we send robots out and they come back in 24 hours and we say, ‘Okay, tell me where you went and what happened to all those bombs you were carrying,’” says Lt. Gen. David Deptula, a retired deputy chief of staff for Intelligence, Surveillance, and Reconnaissance in the U.S. Air Force and the author of the Air Force's road map for UAV integration. “The terminology is important. They're part of a carefully executed system, not independent beings. Autonomous UAVs will be essential for supplementing weapons loads and amplifying sensor information available to human pilots in combat.”

The self-piloting systems, he adds, will also reportedly excel in routine missions and piloting tasks, allowing commanders to more strategically use the human pilots they do have. “Given that we have less than half of the F-22 fighters that we asked for, we need to boost our numbers,” Deptula says. They'll also be able to operate independently should communications be disrupted—or deliberately jammed—which would put a remote-piloted vehicle in jeopardy.

When facing opponents with the technology to interfere with enemy systems and a multitude of ground- and air-based defenses, the advantages of having these options stack up.

THE BATTLE AHEAD

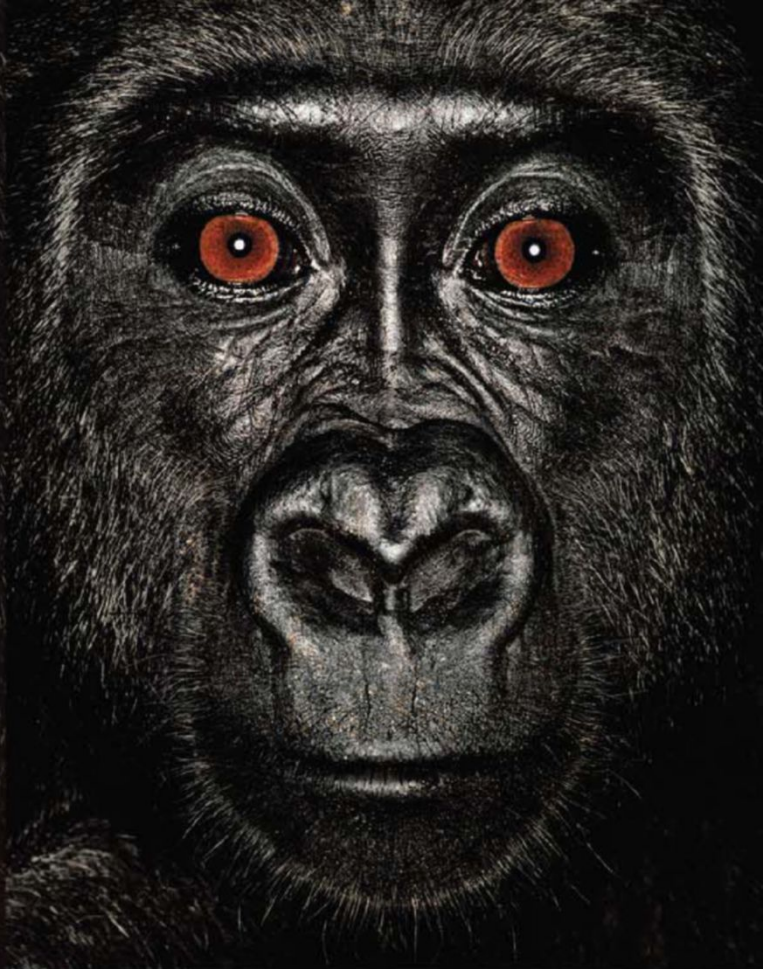
Even with the many advantages that UAVs pose, the relationship between man and machine on the battlefield will remain complex for the foreseeable future. And within the Armed Forces, there are a number of competing visions for how the relationship should unfold. “There are people in the Pentagon who have the right idea about where we have to go in the future, on a practical level,” says Mary Cummings, a former U.S. Navy fighter pilot and systems engineer who now directs the Humans and Automation Laboratory at Duke University. “But there are also still people, even within the Air Force, who have a visceral response to UAVs, and they keep trying to gut the program.”

Of all the armed services, the U.S. Army seems the most amenable to using UAVs. “Perhaps surprisingly, they're the farthest ahead of all of the services in terms of integrating unmanned aircraft,” says military analyst Paul Scharre, a fellow at the Center for a New American Security. “The Army has adopted a concept of manned-unmanned teaming—pairing unmanned aircraft with manned helicopters. It wants to eventually include cooperative multi-aircraft control where one person controls several aircraft at the same time, operating as a ‘swarm’ in surveillance, communications relay, cargo resupply, and close air support missions.”

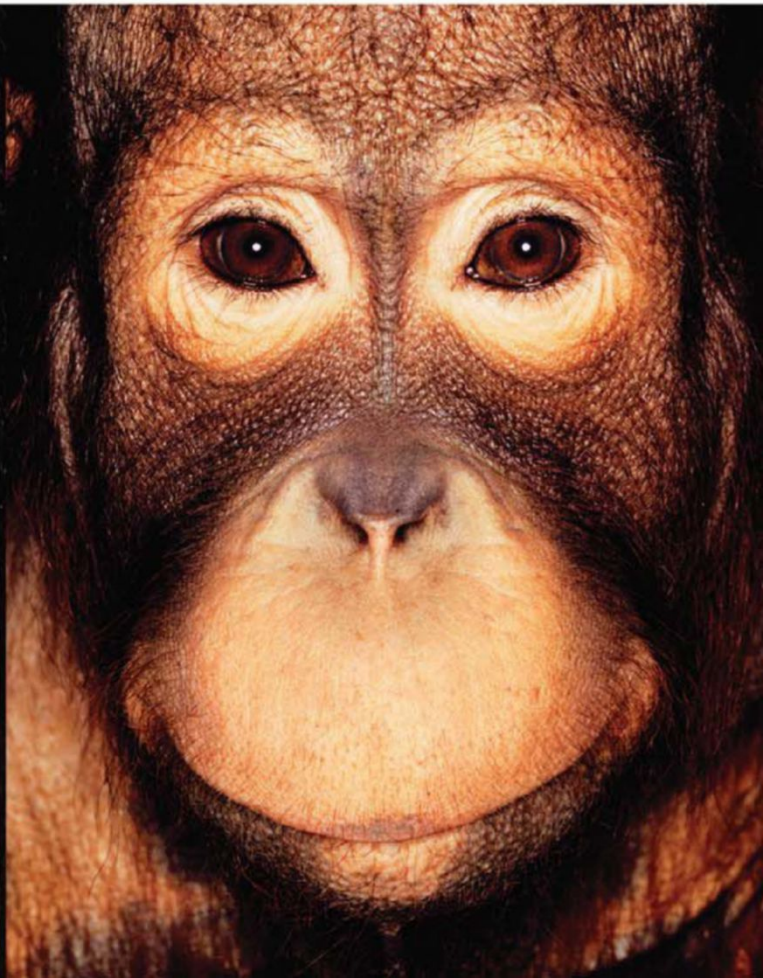
As military technicians start mocking up battlefield plans for future wars, sophisticated tactics like these will likely be necessary to gain an advantage. They may even be essential to victory. But the vision of a unified, cooperative man-and-machine strike force is still missing a crucial component. “All the sensor technology is moving quite nicely into the future. Stealth, autonomy, and aerodynamics are also maturing rapidly,” says Deptula. “The number-one thing we need next is flawless communication—a robust, reliable, secure means of exchanging information. That is the linchpin for developing what I call a ‘combat cloud’ for our campaigns. That's our next great challenge.”



"THE NUMBER-ONE THING WE NEED NEXT IS FLAWLESS COMMUNICATION—A ROBUST, RELIABLE, SECURE MEANS OF EXCHANGING INFORMATION."



ANIMALS LIKE **US**





Humans have always seen themselves as distinct from other creatures. Science is forcing us to reconsider that position.

STORY BY **CHARLES SIEBERT**
PHOTOGRAPHS BY **JAMES MOLLISON**





In December 2013, four captive chimpanzees in the state of New York became the first nonhuman primates in history to sue their human captors in an attempt to gain their freedom. The chimps' lawyers, members of a recently formed organization known as the Nonhuman Rights Project (NhRP), were asking a judge to grant their clients the basic right to not be imprisoned illegally. The NhRP could soon file similar lawsuits on behalf of other great apes (bonobos, orangutans, and gorillas) and elephants—beings that have all been shown to possess highly developed cognitive capabilities.

The NhRP's campaign is, not surprisingly, controversial. For many, the very idea of nonhuman personhood is an oxymoron. Others argue that human rights come with societal responsibilities, such as paying taxes and obeying laws, that no nonhuman could ever meet. Still others feel that current animal-protection statutes offer sufficient security without all the legal and philosophical headaches inherent in extending human rights to another species. The judges of the New York lawsuits ultimately dismissed them all on the grounds that the plaintiffs aren't people. The appeals are ongoing.

Still, the simpler and more profound truth about the NhRP's arguments is that as recently as 10 years ago, they would have been laughed out of any courtroom, derided for being shamelessly anthropomorphic. But now an ever-expanding body of observational, neurological, and genetic evidence about animal intelligence and behavior is forcing us to reconsider the age-old boundary between ourselves and other creatures.

The question of where we stand in relation to animals has preoccupied humans since the dawn of consciousness. The earliest tales told across cultures, among them the creation myths of the Nuer tribesmen of Sudan and the Old Testament's story of Adam and Eve, all pivot around the sudden severance of a

perceived unity between ourselves and other creatures. And the resulting sense of separation has kept us from viewing animals as anything but lesser versions of ourselves.

Early Western thinkers such as Aristotle—composer of one of the first guides to the animal kingdom—wrote of a “chain of being” in which animals, because they lacked reason, were naturally ranked below us. In medieval times, animals became largely abstracted into allegory. The great apes were depicted as “wild men of the woods,” chasers and rapists of women, and thus the very embodiment of our baser, primal selves. In the ecclesiastical courts of the Middle Ages, meanwhile, animals such as pigs, which roamed freely in villages where they often maimed or killed unattended children, were given full trials and even assigned their own lawyers. The guilty party would then be dressed in human clothing and publicly tortured and put to death in the town square: a symbolic ritual meant to reestablish humankind's dominance over animals and restore some semblance of order to an otherwise disorderly world.

A more objective view of animals began to emerge during the Renaissance, but it wasn't until the late 19th century that the first truly scientific study of animals appeared, authored by none other than Charles Darwin. Although he is known almost exclusively for his theory of evolution, Darwin devoted the better part of his life after the publication of *The Origin of Species* to researching and writing *The Expression of the Emotions in*

Man and Animals. Published in 1872 (the same year as the first issue of *Popular Science*), the book paved the way for a series of scientific works on animal sentience and emotion. In the absence of modern research techniques, they were, to say the least, often highly speculative. In one book, the author accords dogs the awareness of “indefinite morality” and asserts that reason begins with crustacea. But these manuscripts also laid the groundwork for the field of comparative psychology, the study of animal behavior. For nearly a century, comparative psychologists developed an intuitive understanding of the shared biological and behavioral bonds between species. Now science is confirming those suspicions in remarkable ways.

Some years ago, I found myself standing inside a large walk-in cooler filled with different animal brains, all of them the property of Patrick Hof, a neuroscientist at the Ichan School of Medicine at Mount Sinai in New York City. There, adrift in glass containers of formaldehyde was a constellation of cerebrums: human, chimpanzee, gorilla, orangutan, spider monkey, bison, and bat. On shelves in the back, Hof kept seaborne brains: dolphin, porpoise, orca, and beluga. Beneath them, a sperm-whale brain rested at the base of a Rubbermaid garbage pail. A gooey white disk, it was roughly the size of a café table.

Hof studies all the brains he can get his hands on in order to better understand the organ's evolution. Along the way he has discovered numerous common features, not just within the human brain and those of our fellow primates, but also in a number of other mammalian species that the NhRP could soon be representing in court.

Not long ago, the different brains in Hof's cooler were as disparate and inscrutable on a cellular level to scientists as

FAST FACT

HIPPOCAMPUS

A region of the brain associated with memory and emotion processing. On a percentage basis, African elephants have the biggest hippocampus of any animal, even larger than humans'.

DID YOU KNOW?

11

The number of brain regions found to correspond between humans and macaques (out of 12 total). A 2014 MRI study from Oxford University revealed the two brains are even more similar than previously believed.

the stars were to early humans. Now there isn't a brain they can look at without considering the common neuronal matter shared by all mammals. Advanced neuroimaging and tissue analyses of the brains of cetaceans, for example, have revealed a very different cerebral construction than our own (owing to the vastly different environments in which the two brains evolved), and yet they exhibit similarly complex cortices and limbic systems. Those areas in human brains are the very ones involved in emotion processing, thinking and perceiving, and language. Hof has also found in both cetacean and elephant brains the presence of highly specialized neurons known as spindle cells. Once believed to appear only in humans, spindle cells are possibly associated with self-awareness, empathy, and a sense of compassion—the kinds of functions long believed to be exclusively our own.

Within the 106-page memorandum filed by the NhRP on

Elephants and whales, for example, the giants of their respective domains, not only have comparably large and complex brains relative to our own; they also evolved them millions of years before humans came along. Both live in multitiered, largely matriarchal societies in which extended groups of mothers, daughters, aunts, and friendly “allomothers” rear and educate their young. They have their own sophisticated languages and songs and, in the case of certain cetacean species like the sperm whale, separate dialects specific to different clans. Both species use tools and foraging techniques and pass that knowledge to other generations, and both grieve their dead—all characteristics of another phenomenon we have long exclusively reserved for ourselves: culture.

It only follows, then, that these creatures also suffer, as we do, from their culture's collapse. Elephants that have witnessed the slaughter of their parents by poaching or culling and lost the support of their extended family group exhibit the same erratic and often detached behaviors as African war orphans who've suffered the loss of their families and the destruction of their villages. Post-traumatic stress disorder, in other words, cuts across species.

Over the entire arc of human thought on animals, the persistent question has been whether they are really like us—whether they are people too. Even as comparative psychology advanced our understanding of animals, we studied them,

ELEPHANTS AND WHALES NOT ONLY HAVE COMPARABLY COMPLEX BRAINS RELATIVE TO OUR OWN; THEY ALSO EVOLVED THEM MILLIONS OF YEARS BEFORE HUMANS CAME ALONG.

behalf of its first nonhuman plaintiffs, nine leading primatologists filed affidavits testifying to the cognitive capacities of chimps, our nearest biological relative. “These include,” the memo states, “their possession of an autobiographical self, episodic memory, self determination, self-consciousness . . . empathy, a working memory . . . their ability to understand cause and effect and the experiences of others, to imagine, to innovate and to make tools. . . . Like humans, chimpanzees have a concept of their personal past and future . . . they suffer the pain of anticipating never-ending confinement.”

The memo also includes an observational study of a chimpanzee in a Swedish zoo who regularly hides an arsenal of stones within his enclosure—ammunition that he uses to throw at zoo visitors whenever the mood strikes him. Other studies show that chimps consistently outperform humans in computer-symbol recognition tests. Comparative genomic analyses, meanwhile, prove chimps share nearly 99 percent of our DNA. Human and chimp blood is interchangeable, allowing for transfusions in either direction as long as blood types match. And a number of brain studies now indicate, among other common characteristics, an abundance of spindle cells, more than in any other species of great ape besides human.

Shared brain structures and complex behaviors may come as little surprise with regard to other primates. But finding them in creatures so seemingly different from ourselves is revelatory.

in no small part, to better understand ourselves. For many decades, our regard for nonhuman creatures went no further than the B.F. Skinner-inspired behaviorist prohibition of anthropomorphism: We can't conjecture about what's happening in their minds for the simple reason that we can't conjecture that about one another.

The most recent science, however, has freed us from that perspective. It no longer matters whether we can truly know what a chimp's day is like, or an elephant's, or a whale's. All the available evidence proves that they have rich days of their own and minds enough to lose. Especially for those creatures currently on the NhRP's prospective clients list, it isn't their likeness to us but their remarkably parallel complexity that must give us pause and command a new regard—certainly a philosophical one and perhaps a legal one as well.

Few cases better reveal the power of science than those put forth by the NhRP on behalf of nonhumans. New instruments and techniques are overturning our understanding of the universe and our place in it. In a sense, we're discovering that the search for complex beings like ourselves has been forever pointed in the wrong direction. Rather than seeking answers in a distant star system, we can find them in billions of years' worth of evolutionary biology. As for the intelligent aliens we've so longed to meet—they have been right here beside us all along. 🐘

HOW GENERAL ELECTRIC, LOCAL MOTORS, AND AN ARMY OF DIY
INVENTORS ARE REBUILDING AMERICAN MANUFACTURING

MAKER

BY TOM FOSTER

PHOTOGRAPHS BY JONATHAN ROBERT WILLIS



Justin Blair, a maker at FirstBuild, operates the Maxiém waterjet in the shop space of GE's microfactory, where products are made in low volume.

R, INC.

I

In a nondescript industrial building near downtown Louisville, Kentucky, in February, a few executives from General Electric Appliances set out to stage the division's first hackathon. Louisville is home to the appliance manufacturer, but rather than hold the contest at headquarters, the executives decided to mount it offsite, in cooperation with the local hacker group LVL1. For the past five years, the group's few dozen members—artists, mechanics, IT folks, hobbyists, and even a few of GE's own engineers—have congregated in a grimy workshop to make such varied projects as

Maker, Inc.

weather balloons and a fire-breathing animatronic pony. On that winter weekend, they would get to exercise their creativity a little differently.

The hackathon's rules were simple: GE Appliances donated refrigerators, ranges, and other devices, and over 48 hours, teams raced to equip them with elaborate new functions. Although the division has a significant R&D budget, Kevin Nolan and Venkat Venkatakrishnan, the heads of technology and R&D, wanted to see what out-of-the-box ideas the crowd might have. The results were alternately silly and useful. One modified refrigerator dispensed soda cans from a chute, like a vending machine. Another used a nitrogen cylinder for home-style flash freezing. ("It had a big sign that said *THIS PRODUCT IS DANGEROUS*—that was their selling point," Nolan says.) The winner, though, was an oven with a bar-code scanner capable of reading and perfectly executing cooking instructions encoded on packaged foods. To demo the product, team leader Chris Cprek, a University of Louisville staffer and one of LVL1's founders, created a bar code with baking instructions for a raspberry pie and used his hacked-together oven to bake the



WHY COULDN'T GE BUILD A MORE NIMBLE PRODUCT-DEVELOPMENT PIPELINE, AND WHY COULDN'T SMART MAKERS HAVE AN ONGOING ROLE?

dessert right on the workshop floor.

To the executives at GE, Cprek's hack was a wake-up call. The idea for a bar-code-scanning oven had come up in internal ideas sessions before, and they knew it had great potential. Such an appliance could help people eat healthier meals without requiring much time or expertise. And yet the concept had never left the brainstorm stage at GE. That's because, for giant manufacturing companies, putting something into a production run is a huge gamble. Moving an idea through the obstacle course of various departments (R&D, design, market research, manufacturing) can take years, and tooling a factory line can cost tens of millions of dollars. That the executives were now staring at a working prototype of an idea they already liked—from an outside source—made them wonder how much innovation they were letting slide by. Why couldn't they build a

more nimble product-development pipeline? For that matter, why couldn't smart makers like Cprek have an ongoing role?

Six months after the hackathon, Nolan and Venkatakrishnan explain how that line of questioning led to the new, GE-owned hackerspace called FirstBuild. Partly inspired by the LVL1 contest, FirstBuild launched with the help of some of the biggest names in the U.S. maker movement—primarily Local Motors, an open-source automotive manufacturer, but also the 3-D-printer company MakerBot and the makerspace chain TechShop. FirstBuild will serve as a bridge between the hacker movement and the mass market, pairing a global online community with a 33,000-square-foot public hackerspace and small-scale factory. As ideas bubble up from the crowd, either from the online community or in the hackerspace itself, creators can team up with GE

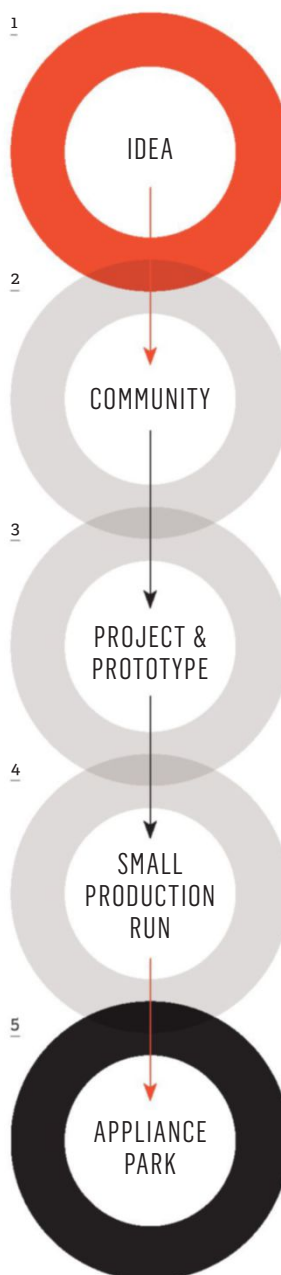
designers and engineers to build prototypes. If enough interest for them develops online, FirstBuild will put them into a limited production run for sale under its brand. If those products do well, they could graduate to GE and go into mass production.

The FirstBuild community went live in May, and when Cprek posted his bar-code oven, it quickly became one of the most commented-on concepts on the site. He is now working with GE engineers to turn it into an actual product. That would be a big deal for Cprek, but more to the point, it would be a big deal for GE. If the company can harness the brains of makers around the world and speed their ideas into testing and production, it could become the fastest, most innovative home-appliance maker in the industry. And if the FirstBuild model works for appliances, it could be applied to GE's other divisions, such as aviation,



HOW TO CROWDSOURCE AN APPLIANCE

FirstBuild brings makers together in both an online community and a 33,000-square-foot workshop. The goal: to remake R&D with help from the masses.



A maker proposes a new product or a modification to an existing product in one of three places: at the physical FirstBuild makerspace in Louisville; on FirstBuild's website; or in physical facilities or online forums of the partner companies TechShop and MakerBot.

Once an idea is posted to the FirstBuild site, members can vote for favorites, improve on ideas, or (if they're in Louisville) help build early prototypes in the workshop with 3-D printers and woodworking tools.

When a design gains traction with the FirstBuild community and GE leadership, it can be named an official project. Then GE engineers and designers will help create a more sophisticated prototype using laser cutters and large-scale 3-D printers.

If that prototype shows promise, it can enter a limited production run in the micro-factory behind the workshop at FirstBuild headquarters. Dozens of units can be made, and then sold in the FirstBuild showroom and online.

If the small product run goes well, the idea can be sent down the road to Appliance Park to be made by the million. It will still cost GE a considerable sum to tool a large factory, but the risks of a product failing will be much lower.

Engineers Justin Brown and Tim Gillespie talk in front of an audio speaker they made in FirstBuild's workspace.

health care, and oil and gas. For a company widely regarded as a proxy for American manufacturing, such an experiment could mean a lot more than an improved bottom line. It could help accelerate a new movement in U.S. industry, one in which jobs and innovation come back to stay.

The story of American manufacturing is, in many ways, the story of GE's Appliance Park. Built in Louisville in the postwar boom of the 1950s, the factory park provided a rapidly suburbanizing population with a steady stream of gleaming refrigerators, stoves, washer/dryers, and dishwashers. A symbol of American industrial might, the park was so big it had its own zip code and post office. At its peak in the early 1970s, its 7.6 million square feet of building space housed 23,000 employees a day. The parking lot spanned a full mile and included stoplights.

Three decades later, Appliance Park had just 1,300 employees. Buildings sat empty; at least one had holes in the roof and defunct plumbing. "It was depressing," says Nolan, who has worked at GE for 25 years—his entire career—17 of them at Appliance Park. "Building Two was closed for like 15 years. It was dark and scary; you didn't want to go back there." In large part, that decline can be traced to a single root cause. Through the eighties and nineties, millions of American manufacturing jobs went overseas. Lured by low labor costs and lighter regulation, many companies pulled out of American manufacturing centers such as Detroit, Cleveland, Pittsburgh, and, of course, Louisville. To do otherwise would have been uncompetitive, something shareholders don't care for.

Yet, as the years wore on, the very move that heightened competitiveness began to erode it. The outfits that did contract manufacturing for U.S. firms—Samsung and LG, for instance—began making their own high-quality products. What's more, rising fuel and labor costs started to cancel out any savings gained by outsourcing, while innovation and speed to market suffered. With U.S. design and engineering teams separated from manufacturing by 5,000

Maker, Inc.

miles, companies were stuck with slow, inefficient operations that too often turned out subpar products.

For GE Appliances, the situation got so bad that in 2008, CEO Jeff Immelt considered selling the division outright. Instead, he decided to double down. Immelt committed nearly \$1 billion to reviving the division, taking advantage of American skilled labor and the proximity to customers. Since 2010, more than 3,000 people have been hired at the reinvigorated Appliance Park, and every building hums with modern production lines.

Like any state-of-the-art factory, the new Appliance Park was devised as a bastion of “lean thinking”—a disciplined approach to efficiency, continuous improvement, and rapid iteration that Toyota made famous. But going lean was only a partial solution to GE Appliance’s woes. To avoid discarding ideas like the bar-code oven, GE Appliances also needed to act more like a start-up. “If you



**“WE THINK THE NEW INTELLECTUAL
PROPERTY IS SPEED. PEOPLE WHO CAN MOVE
FAST ARE GOING TO WIN.”**

want to build minimum viable products and fail fast, and you’re trying to make a million dishwashers . . . that’s not going to happen,” Nolan says.

Around the same time that Nolan and Venkatakrishnan were courting the hackers at LVL1, Beth Comstock, GE’s chief marketing officer, also began to wonder what benefits the maker movement might hold for a major manufacturer. Comstock has the easy smile and calm confidence of a natural networker, and she makes a point to introduce Immelt to unconventional thinkers. Once, she brought in Jay Rogers, the co-founder of Arizona-based Local Motors. Rogers wowed Immelt with his model for community-based product development and small-scale, distributed manufacturing. An Iraq war veteran with a Harvard MBA, Rogers didn’t look or sound like a business hippie. What he explained, leaning into the conversation with a Marine’s intensity, was a highly disciplined process that just happened to be the exact inverse of everything GE traditionally did.

Local Motors uses an online platform to crowdsource vehicle-design and engineer-

ing ideas, which it then prototypes in small, open-access factories (there are currently two, with more planned). The process shouldn’t work—design by committee is usually a recipe for dulling ideas, not sharpening them—but Local Motors has achieved some interesting successes. By using in-house expertise to channel the wisdom of the crowd, the company launched the world’s first open-source vehicle—a street-legal, off-road rally car with the comfy interior of a commuter model—a series of special-interest motorcycles, and the first vehicle ever 3-D printed. It took much less time than it would’ve taken traditional automakers, and because Local Motors doesn’t need to tool up giant factories, it did so at a fraction of the cost.

Along the way, Local Motors also forged a few high-profile partnerships, most notably with the Department of Defense’s advanced research arm, DARPA, which enlisted Local Motors to design and prototype a high-speed recovery and resupply vehicle for combat situations. Within four months—ahead of deadline—the company delivered a prototype called Flypmode. President

Obama was impressed, and said so: “Think about it. Instead of having a 10-year lead time to develop a piece of equipment, if we were able to collapse the pace at which that manufacturing takes place, that could save taxpayers billions of dollars. But it also could get technology out to the theater faster, which could save lives.”

Unsurprisingly, that kind of praise caught the eye of GE. “We figured, if it’s good enough for the DOD, it’s good enough for us,” Comstock says. And so as plans for FirstBuild moved forward, GE approached Local Motors with a proposal for a formal partnership. The manufacturer was excited at the prospect of saving serious money while becoming more nimble. And for Rogers, the partnership would be a way to prove, on the biggest stage, that his model is something more than a novelty. But before signing, he had a condition. Rather than employ select parts of the Local Motors model, as DARPA had done, GE would have to re-create Local Motors’ process entirely. “I’m not doing anything unless you are all in,” Rogers said to Immelt. And so FirstBuild was born.



From left: FirstBuild's TouchFlo Disposer; ChillHub, a USB/Wi-Fi-connected fridge; maker Keith Wait at work

The night before the FirstBuild grand opening, the bar at the 21c Museum Hotel in downtown Louisville is buzzing, and a veritable Super Friends of the maker movement stands clustered at its center. Bre Pettis, founder of MakerBot, wears a bushy new beard and a mop of salt-and-pepper hair with his chunky geek glasses. Jay Rogers loiters opposite him in a flight-suit-style jumper with the Local Motors insignia embroidered on the breast. TechShop CEO Mark Hatch is here too. They've just come from a dinner with GE's Nolan, Venkatakrishnan, and Comstock.

About a month earlier, at the White House's inaugural Maker Faire, GE announced that, along with Local Motors, it was bringing MakerBot and TechShop into the FirstBuild fold. MakerBot's 3-D printers will allow members of the FirstBuild workspace to quickly prototype components. "But the really exciting part will be getting existing MakerBot users involved," says Pettis. By posting projects to the company's popular website, Thingiverse, FirstBuild will dramatically increase its reach. In turn, thousands of MakerBot users will get new, real-world projects to work on.

For TechShop, which operates a chain of maker workshops in cities including San Francisco, Austin, Pittsburgh, and Detroit,

the partnership is also a means to engage its community. In each TechShop location, a dedicated kiosk will grant makers access to FirstBuild projects. "It gives the maker community a purpose," Venkatakrishnan says. "We throw open a CAD [computer-aided design] model and say, 'Here's what we're working on, and here are the problems or questions. How do we figure these out?'"

That straightforward approach has been good for the maker community. "FirstBuild has been a great resource for us," says Cprek, who spends about an afternoon a week in the workshop fine-tuning his bar-code-scanning oven. "They have all these people around who have formal training, like former GE engineers. They know the ins and outs of manufacturing, and they're great folks to bounce stuff off of."

But this spirit of openness raises questions too. If FirstBuild is an innovation incubator, doesn't such transparency tip off the competition? "That's something the company has to wrestle with," Nolan says. "But really, what's the future of intellectual property [IP]? The IP system was built to spur innovation, but there's an argument now that the opposite is happening—that it's stopping people from innovating [because of bureaucracy and excessive litigation]. The whole maker movement is looking that in the face. And we can't sit in a closet and ignore it. We think the new IP is speed. People who can move fast are going to win."

That's why FirstBuild adopted Local Motors' payment method to incentivize good ideas. Contributors receive 1 percent of the sales proceeds from their work for three years, and they get to keep the IP; if Samsung wants to buy their ideas the day after they give them to FirstBuild, so be it. To manage the system, FirstBuild tracks those contributions that become part of a final product and values them separately. Since most contributors will design product modifications rather than entirely new products, they will be paid 1 percent of the value of that modification, not of the whole thing.

It's unlikely anybody is going to get rich on that system—other than, perhaps, GE. But it's also unlikely an individual maker would have access to trained designers and engineers and a GE Appliances production line. "Look, every inventor has a dream that their idea is going to be big," Nolan says, "but trying to do that on your own, it's very hard to scale. That's what we know how to do. Literally five miles from FirstBuild we have 6 million square feet of factories."

From the outside, it sounds like a lot of work to manage payments to thousands of contributors, but GE Appliances stands to gain a lot. If a FirstBuild product makes it to a production line in Appliance Park, the division will still have to spend millions to set up a supply chain, make molds and dies, and configure the heavy equipment. But that product will already have been market-tested and refined in a low-volume facility—a tremendous advantage. "Big companies don't have a way to work in low-volume scenarios," Nolan says. "Start-ups are used to it, and they have trouble growing up. Big companies are used to high volume, and they have trouble starting up."

Take, for example, Cprek's oven. GE would have spent two years and up to \$10 million to get it into production. By comparison, Venkatakrishnan estimates that developing the product and manufacturing a small run of 20 test ovens to sell through FirstBuild will take no more than six months and cost less than \$50,000. The investment in eventual mass production (if it happens) will still be expensive, but it could come more than a year

continued on page 72

Norman Rockwell and Other American Icons

These are people that influenced my life in New Rochelle, NY where Norman Rockwell lived for 25 years and where my family lived for 3 generations.

We all knew and loved the man in spite of a book trashing him in another attempt to destroy everything that is great about America! I am writing a book with a rebuttal that includes the untold stories about many others that shaped our country.

Did you ever wonder what happened to over 100 signed letters from FDR, that Harvard wanted for their archives?

Most of these people I met in my parents living room: Dr. Norman Vincent Peale, James Cash Penney, Lowell Thomas, Charles E. Wilson (Chairman of GE, FDR appointed him head of the War Production Board WW2), Carrie Chapman Catt (Woman Suffragist), Dr. James E. West (Chief Scout Executive, Boy Scouts of America), William Frank Snyder (FDR's lawyer and close friend, who also had polio, wrote his will and handled his financial affairs including Mrs. Delano, complaining to my mother: "The Roosevelt's are using my pool!"). "Buffalo Bob" Smith (It's Howdy Doody Time!). C.L. Lowes: (My grandfather started BOND

BREAD. Buying trainloads of flour for 50 plants, he waited for the price of flour to go UP so farmers could make a fair profit...he was unique! General Baking Co became General Host..."Twinkies") Richard Ellis (my brother, commercial Real Estate) and many others!

After my father died, Dr. Peale said the eulogy and inspired me to increase water properties back to what it was before "The Flood" (living to Biblical ages). After "The Flood" they didn't live as long!

Since I am the first person in history to do it, should be ample proof that it had to come from divine inspiration! With an Engineering Degree that includes Steam Plant Design, I increased the Hydrogen Bond Angle (HBA) in ordinary water from 104 to 114 degrees, confirmed by scientists at Los Alamos Nuclear Lab and Lawrence Livermore to The Washington Times.

The Washington Post (on our website): "10,000 people per day" traveling to obtain water from my countertop machines, even adding water to a well with miraculous results! Dr. G. Abraham MD UCLA: "Nothing is even close for measurable Blood Flow with a 114 HBA!" At 84, MEASURE 3000% more ENERGY in your drinking water (Video)!! 13 Patents 332 FDA Tests johnellis.com/measure



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Gilbert de Daunant (Prince Rainier's cousin): "I just walked 40 blocks and I am 94! Send another E5 to Monaco!"

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You don't need an army to wage an epic snow battle. This sled-mounted slingshot provides a tactical advantage. You can easily haul it from one strategic position to the next as you fire a fusillade of snowballs with accuracy and speed that would impress a general.

Flexible rubber tubing acts as a powerful tension spring for flinging ammo, while a midweight sled forms a steady base to stabilize the contraption. Don't want to turn a perfectly good sled into a weapon? You can easily construct your own base from standard lumber using simple hand tools. **WILLIAM GURSTELLE**

LET IT SNOW

The "snowball" in the photo is made from (unused) disposable diapers. Just rip open the fabric, shake out the ultra-absorbent polymer within, and gradually add water.



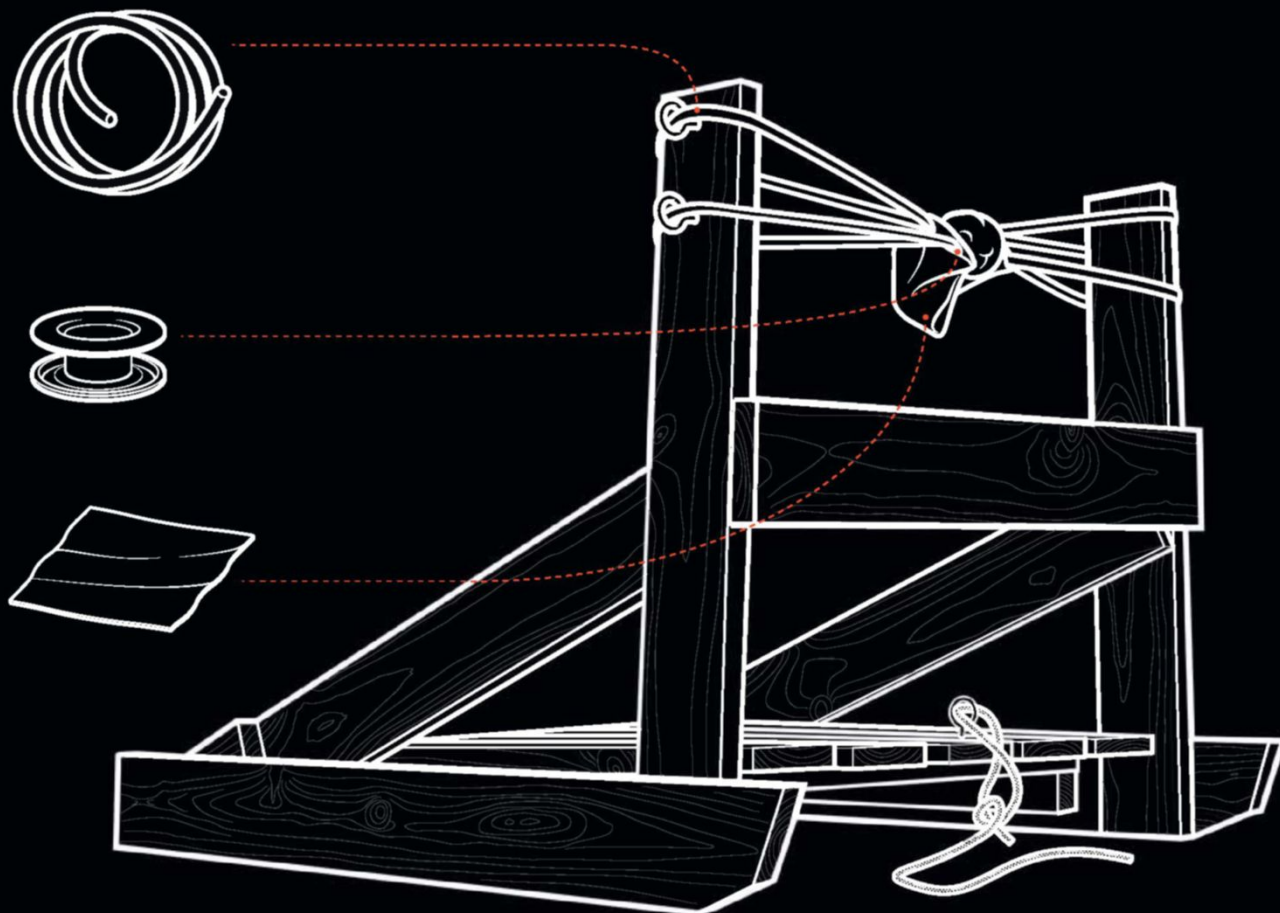
WARNING: Don't overextend the tubing or fire a projectile at close range. It will hurt.

To build the sled base from scratch, see instructions and drawings at popsci.com/snowballslingshot.

continued on page 64

Build It

continued from page 63



MATERIALS

• Wooden sled	1" x 4" x 36")	(1/4" ID, 5/16" OD, 1/32" Wall)
• Pieces of pine:	2 pads (1" x 4" x 4")	• 5 large screw eyes
2 posts (1" x 4" x 24")	1 cross support (1" x 4" x 24")	• 1 1/4-inch nails
2 braces (1" x 4" x 30")	• 7" x 4" piece of sturdy fabric	• 5 medium-size metal grommets
2 runners (optional)	• 10 feet of latex tubing	• 4 feet of rope

TOOLS



Hammer



Grommet kit



Scissors

INSTRUCTIONS

1 Depending on your sled, you may be able to nail the posts and braces directly to its sides. If not, nail the runners to the sled's deck, one on each side and about 22 inches apart, to create a stable base.

2 Nail the posts and pads in parallel on each side of the base. The posts should be near the front of the sled, with the pads 18 inches behind. Then nail the braces in place so they connect the tops

of the posts to the pads.

3 Hold the cross support horizontally so it connects the two posts, about halfway up each one, and nail in place. At the top of each post, twist 2 screw eyes into the outside edge in a vertical line, 2 inches apart.

4 To make a launch pouch out of the sturdy fabric, puncture the four corners and the center with the grommet kit's hole punch.

Insert the taller grommet half beneath each hole, facing up. Cover it with the other half, facing down. Position the kit's mandrel above the grommet with the anvil below. Then strike sharply with a hammer.

5 Insert the latex tube through one of the upper screw eyes, and thread through the grommets on the pouch's upper edge. On the opposite side, run the tube through the upper screw eye, then the lower screw

eye. Next, thread the tube through the grommets on the pouch's lower edge and the final screw eye. Adjust the tubing so the tension on both sides is about equal. Tie securely and tape the ends so the knot doesn't loosen.

6 For a pulling handle, insert about a foot of rope through the central grommet and secure with a knot. The rest of the rope, threaded through a screw eye at the front of the sled, can form a towline.

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Biohacks



The Anonymity Artist

↓
Two years ago, artist Heather Dewey-Hagborg caused a stir in both the art and biosecurity worlds when she displayed busts of people she'd never met. She determined the facial features for her "Stranger Visions" show using DNA found in the streets and subways of New York City. "We are shedding our biological information all the time without knowing it," Dewey-Hagborg says. "I think anonymity should be a choice." She devised her next project with that thought in mind. The pair of perfume-like sprays she invented, called Invisible, obscures DNA traces so no one can follow your genetic trail. **DANIEL GRUSHKIN**

Stranger Visions

Discarded cigarette butts, gum, and hair provided Dewey-Hagborg with DNA, which she tested for genetic variations that reveal a person's gender, ethnicity, eye color, and facial structure. Software she designed used that data to build model faces, subsequently 3-D printed in plastic.



Invisible

Dewey-Hagborg's genetic-invisibility spray comes in two sleek bottles that work in tandem. "Erase" contains a solvent, such as ethanol, that destroys 99.5 percent of DNA left on a surface. "Replace" masks the remaining 0.5 percent with a blend of DNA from 50 different sources.

12 | Nanograms of DNA in a micro-liter of saliva

Tech Support

Q: CAN WE CREATE A REALISTIC DEER ROBOT TO NAB OFF-SEASON POACHERS?

—Florida law enforcement

A:

If you want to fool experienced hunters, your robot needs to move its head, tail, and ears independently. Start with a taxidermied deer. Cut off its movable parts, install a four-channel radio-control system, and reassemble the animal. One channel can turn the head back and forth, another can flip the tail up and down, and a third can rotate the ears. Then set up your robo-deer near a forest and get ready to catch anyone who takes a shot.

—Jim Smentowski, [The Robot Marketplace](#)



The bionic Bambi was so convincing it took multiple bullets, eventually requiring replacement parts. **ALISSA ZHU**

A Reflux Still for Making Moonshine

180

Proof of the
alcohol the still
produces

WARNING: Distilling alcohol is a federal offense and violates state laws. Some exceptions are made, but apocalypse prep isn't one...yet.

Hackett is *Popular Science's* intrepid DIY columnist.



In times of chaos, alcohol is a rare commodity that has universally recognized value. It can fuel engines, clean wounds, and ease social interaction. It's also shockingly easy to make.

The first step is fermentation. Yeast cells are not good planners. If you put them in a container fitted with an airlock, they will gobble up sugar and churn out carbon dioxide and ethanol. Within a few weeks, they will fall to the bottom, killed by their own waste. This leaves us with a potent metaphor and, if conditions are right, a beverage of about 5 to 15 percent alcohol.

In the past, I have made the mash, or yeast feedstock, from Dumpstered candy bars, a truckload of overripe plums, and an industrial bakery's disgustingly sweet pastry filling. Luckily, distillation gets rid of flavor. It also boosts the alcohol content from slight buzz to rocket fuel. You are now entering the glamorous world of federal crime. *Proceed at your own risk.*

My reflux still uses propane to heat a stainless-steel keg of fermented mash. Ethanol turns into steam first, rising through a metal chimney to a cocktail shaker containing a copper coil. As a pump runs water through this assembly, it acts as a condenser, cooling the vapor until it drips out as liquid spirit. Discard the first few ounces to avoid methanol—and blindness.

As the temperature rises, water boils, diluting the vapor. That's why I packed the chimney with copper pot scrubbers. They give the water molecules plenty of surface area on which they can condense and leak back into the pot, while the concentrated ethanol continues up to the cocktail shaker. This creates multiple distillations—hence *reflux* still.

The booze that finally emerges is close to pure ethanol: It will run a gasoline engine. For sipping, I water it down to 130 proof—a strong punch in the face, but surprisingly delicious.



Hackertainment

3-D PRINT A DAFT PUNK HELMET

It was 18 years ago this month that Daft Punk released their first studio album, *Homework*. The electronic-music duo's robotic persona recently inspired Pedro Ruiz, creative technologist at Adafruit, to do a little homework of his own. It took Ruiz three days, and enough plastic to stretch the length of three football fields, to 3-D print a replica of Daft Punk's trademark helmets. For extra pizzazz, he added programmable LEDs. Even non-fans can enjoy the helmet, Ruiz says: "It's great for scaring your small child when they act up!" **AMANDA SCHUPAK**

PRINT IT

Customize the 3-D-printing files to fit by measuring your head just above the ears. Get links at popsci.com/printpunk.

LIGHT IT

Ruiz glued six battery-powered LED strips inside the plastic visor and taped over it before painting the rest of the helmet gold.

WEAR IT

While the visor shows off the LEDs, it doesn't allow clear vision. Ruiz's tip: "Have a friendly spotter to watch where you step."

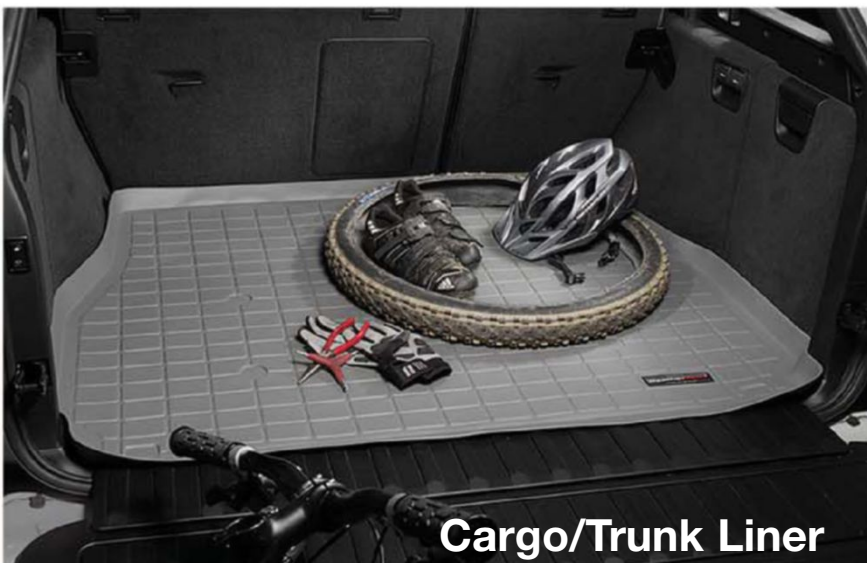


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WeatherTechEurope.com

**Killer App****DRONE-MADE MAPS**

Any drone can snap photos of a house from above. But what if you want a detailed map of your entire neighborhood? No problem. Aerial-imagery specialist Tudor Thomas and his colleagues developed Maps Made Easy, an app that stitches drone photos into a map with resolution up to 20 times that of Google Earth. Before the rise of drones, such detailed cartography required airplane- or chopper-based rigs, which can cost millions of dollars (not counting the price of the vehicle). This app has a processing fee, but mapping more than 60 acres costs less than \$15.

ANDREW ROSENBLUM

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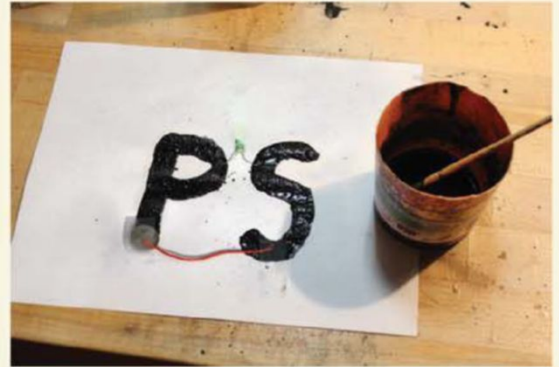
Liberate your next electronics project from the constraint of wires and run current through a painted line of graphite instead. A DIY graphite paint won't conduct electricity as well as a wire or an expensive commercial conductive ink. But it's perfectly good for connecting LEDs to batteries in flexible circuits and making a sheet of paper touch-sensitive enough to play like a piano keyboard. **JEREMY COOK**

MATERIALS

- Powdered graphite
- White vinegar
- Syringe
- Clear Elmer's glue

STATS**Time** 2 hours**Cost** \$12**Difficulty**

• • • • •

**INSTRUCTIONS**

- 1 To make the ink, put powdered graphite in a cup, cover with vinegar, and stir. Let it sit for a few minutes.
- 2 Once the graphite settles on the bottom of the cup, remove the clear liquid on top with a syringe.
- 3 Stir in about a teaspoon of glue to keep the graphite suspended. A thick line of paint has a resistance of a few kilohms per inch.
- 4 To test, use a small brush to draw lines connecting a 3-volt coin cell battery to an LED. Let the circuit dry and watch it light up!

FROM LEFT: COURTESY MAPS MADE EASY; COURTESY JEREMY COOK

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ANSWERS BY **Daniel Engber**

ILLUSTRATIONS BY **Jason Schneider**



Do plants get sexually transmitted diseases?

Short answer Sure, all the time.

A Researchers have long known that certain fungal parasites can spread from one flower to another via pollen transfer. And like most animal STDs, plant STDs aren't usually fatal for the individual host plant. Still, the concept of "sexually transmitted diseases" doesn't fit neatly into the plant kingdom.

For one thing, the infections are not transmitted through direct physical contact, as in animals. Typically, the fungal spores make their way from plant to plant on gusts of wind or by hitching a ride on a pollinating insect. The best-studied plant STD is *Microbotryum violaceum*, a pathogen that affects

flowering plants called campions. Both the male and female flowers of plants infected with *M. violaceum* serve as breeding grounds for the fungal spores, which can then be spread by bumblebees and other pollinators. The fungus may even stimulate a diseased plant to produce extra flowers in order to spread the infection more efficiently.

Swedish botanists Anders Wennström and Lars Ericson have studied other flower fungi, including some that make their way from a bloom into the soil, where they can infect another generation of plants the following year. And certain fungal parasites are passed from the flowers of one plant to the seeds, leaves, or stems of another. But since the pathways of these infections don't require that both plants have sexual organs, it's not clear that the diseases should be categorized as sexually transmitted. The researchers suggest that they be called reproductive diseases instead.

Are there electronic defenses against drones?

Short answer Yes, but they're pretty much illegal.

A

In 2012, a small robotic helicopter, painted Texas Longhorns orange and white, climbed into the air above the team's empty football field in Austin. Then the device suddenly plummeted toward the grass, its controller overridden by a team of university-sanctioned hackers. A few days later, in the White Sands Missile Range in New Mexico, the same group (with permission) hijacked the university's \$80,000 military-grade drone.


"No one had ever done the attack that we did before," says Todd Humphreys, director of the Radionavigation Laboratory at the University of Texas at Austin. At least not in the declassified world. But that doesn't mean it's not easy to replicate. Humphreys's team used a relatively basic hand-built radio device to exploit a major loophole in drone security: the devices' reliance on unauthenticated position data beamed from GPS satellites.

Both civilian and military systems rely on these transmissions, but only the latter use waveforms resistant to spoofing attacks. Civilian GPS data aren't only unencrypted; the signals' specifications are publicly available. Hackers can fool a civilian drone with counterfeit signals made to look like normal satellite transmissions, coaxing its onboard software into making bogus course corrections so it moves just how the hackers want it to.

Less tech-savvy privacy nuts could take a simpler approach, jamming a nearby drone instead of hijacking it. "It's off-the-shelf easy," Humphreys says. "For \$100 you can buy a GPS jammer over the Internet that does the job just fine in a two-mile radius. And if you've got a nice vantage point, on top of a mountain or a building, you can knock out GPS over an even broader area," he says.

Such attacks could also hinder in-car

satellite navigation and smartphones, not to mention elements of the U.S. banking system and the nation's energy-distribution network. "We have this stealth dependency on civilian GPS," Humphreys warns. It's illegal to send out jamming signals, just as it's illegal to launch a spoofing attack, "but the law isn't terribly enforceable," he says. A determined troublemaker could jam signals without much risk of getting caught, provided he or she switched locations every couple of hours.

Humphreys thinks regular Joes will want to defend their privacy too. "There will be a subculture that rejects the notion that Amazon drones are flying over their backyards, delivering packages to their neighbors," he says. A few may use high-tech attacks to capture drones and keep them as trophies, he says, but most will take a more "down-to-earth" approach: "I have the sense that a shotgun is going to be the first thing they'll grab, not a jammer or a spoofer." 



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Maker, Inc.

continued from page 61

and a half sooner, with much less risk of failure. As Jay Rogers puts it, "We're going to see if we can make an elephant dance."

In September, GE agreed to sell its appliance division to the Swedish company Electrolux—and FirstBuild along with it. It was a blow to supporters but hardly a referendum on the idea. If Nolan sees FirstBuild as a laboratory for product innovations that could spread to Appliance Park, Comstock sees it as a laboratory for innovation that will spread to other parts of GE. What's more, while FirstBuild proper is being sold, the actual partnership with Jay Rogers and Local Motors is with GE's corporate arm, so efforts to expand the relationship continue. "FirstBuild came together so quickly that it's already a beautiful proof point," Comstock says. "A lot of other GE engineering teams have gone to Louisville to figure out how they can adapt it." She says the company will roll out the FirstBuild model in other divisions, perhaps before the end of the year.

Rogers sees opportunity in every sector of GE's \$100 billion business. But the model of crowdsourced development extends

well beyond one company, he says. Any enterprise shackled to a slow and expensive production model could benefit from low-cost, fast-paced innovation. Indeed, if outsourcing was a major cause of competitive advantage over the past 30 years, rapid development, low-risk manufacture, and proximity to markets could take its place over the next 30. For American manufacturing, that bodes well. The nation is still home to some of the world's largest markets and manufacturers, and it still harbors some of the brightest, most entrepreneurial minds. The FirstBuild model brings those elements together in a system that could fit any number of organizations. As Rogers says of GE Appliances, "If we can do it here, we can do it anywhere."

As for FirstBuild, since the online community launched in May, it has signed up several thousand members—many more than expected. "For makers, if you're looking to take something to the next level—to dot I's and cross T's with the intent to move into a much grander venture—then FirstBuild is great," Cprek says. To channel the energy of the crowd, FirstBuild has so far issued two



official challenges. One is to design a fully functional microkitchen for tiny apartments in dense urban areas, and the other is to dream up a new, smokeless way to grill indoors. Both have already produced promising designs.

Nolan, meanwhile, proposed an idea of his own. He wants to create an electronic pizza that can measure the exact conditions within a restaurant-grade pizza oven, so that the company can re-create them in a home oven. An engineer by training, he's letting his hacker flag fly and chasing an idea just because he thinks it's awesome. "I'm from New York, and you get the best pizza in the Bronx," he says. "Those ovens get really hot, and there's a bunch of folklore about the convection that happens. So we want to go to the best pizzeria and put a digital pizza in the oven. What's really going on?" Nolan pauses and asks the next logical question: "Why can't we build that?" ❧

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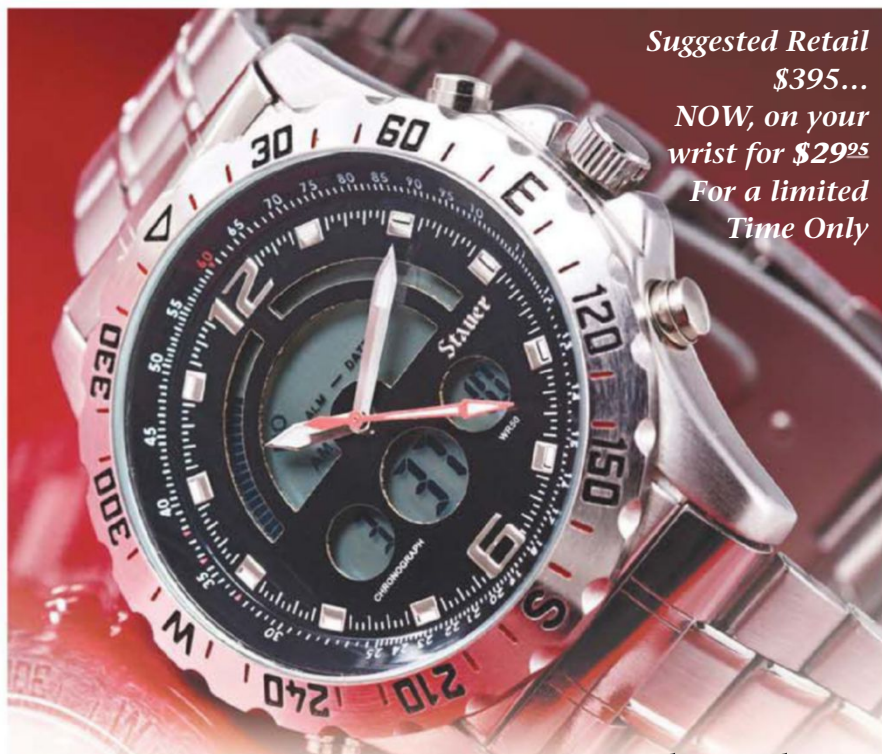


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From the Archives

Stealth Flight Comes Into View

When *Popular Science* featured the Advanced Technology Bomber on the September 1986 cover, it was before the military revealed what it looked like. As we wrote then, "To those outside the black curtain of Pentagon secrecy, making out the stealth picture is like assembling a jigsaw puzzle with only 10 percent of the pieces." Still, we used those pieces to investigate how the right combination of shape and material could render planes invisible to radar, and the craft we envisioned proved remarkably similar to Northrop Grumman's B-2, which was unveiled two years later. In this issue, we analyze clues to a new class of stealth vehicles: unmanned autonomous drones, such as the RQ-180, also made by Northrop Grumman. For more about today's arsenal, turn to page 46.

ALISSA ZHU

How Aircraft Hide

RADAR

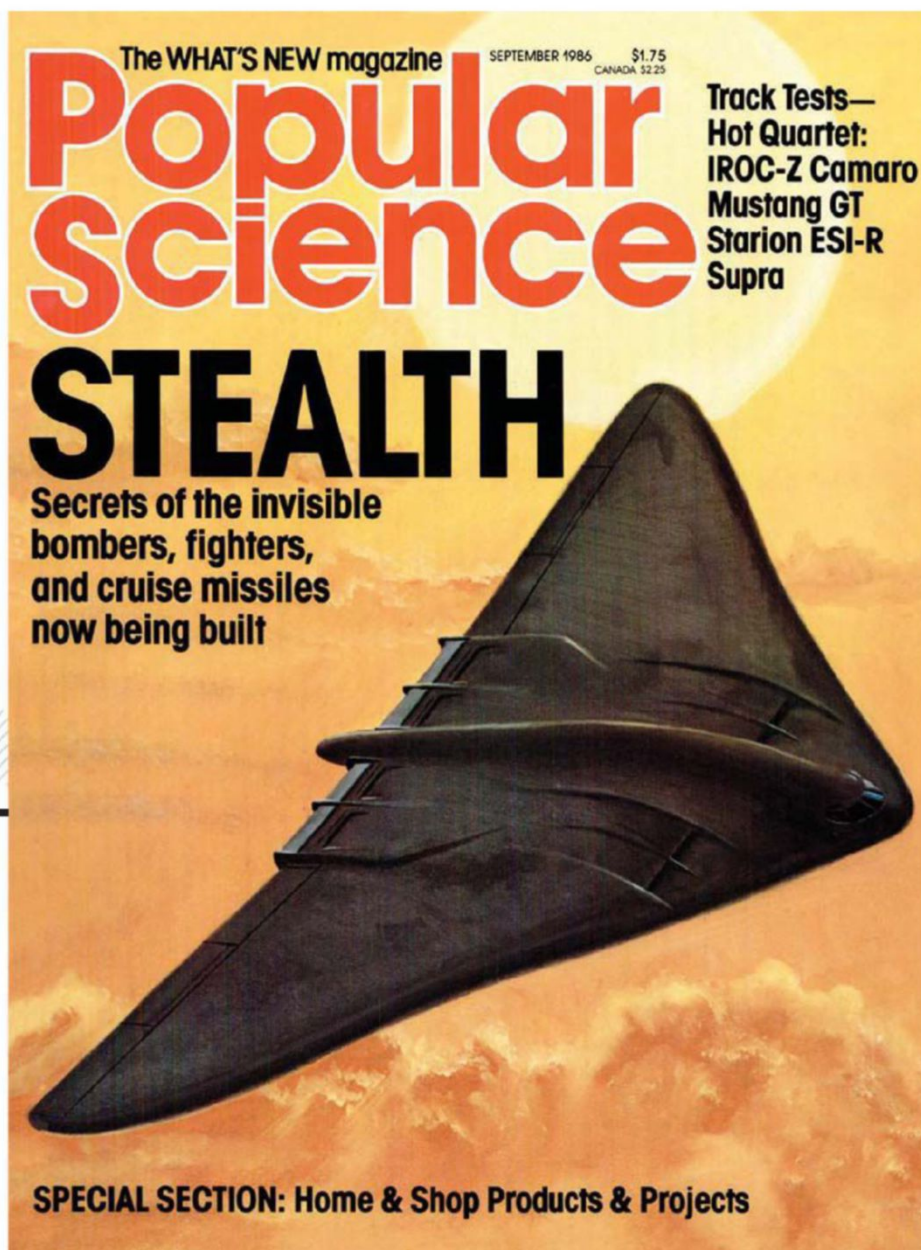
A precisely sculpted shape paired with radar-absorbent material dissipates radio waves, giving planes like the B-2 the radar presence of a small bird.

INFRARED

Stealth craft have slits in the tailpipes that quickly mix hot engine exhaust with cool air, lowering their heat signature.

VISIBILITY

Combining jet exhaust with chemicals that prevent water from condensing eliminates contrails—the white trails of vapor that form behind planes.



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